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Potential of Biomass in Developing Renewable Energy: Wood Pellet Trade from US and Development of Aviation Fuel from Oilseed Crops

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To the Graduate Council:

I am submitting herewith a thesis written by Umama Rahman entitled "Potential of Biomass in Developing Renewable Energy: Wood Pellet Trade from US and Development of Aviation Fuel from Oilseed Crops." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural and Resource Economics.

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Abstract

Interest in renewable energy is increasing all over the world. The use of biomass as renewable energy is also rising. Different policy initiatives and targets incentivize the growth of renewable energy as well as the use of biomass for renewable energy. This study assesses the potential of biomass in the export market and evaluates the potential of energy crop within the United States (US). The first chapter of the thesis gives a broad introduction of the study. Furthermore, the second chapter examines factors and renewable policies that affect wood pellet export by US using a commodity specific gravity model. A monthly panel dataset of 11 countries of wood pellet export quantities is examined. The results suggest that importer renewable electricity production, US Gross Domestic Product (GDP), and US renewable energy policy which incentivites to US wood pellet production positively affect US wood pellet export, while importer's research and development policy for their wood pellet production and the trade regulation policies for biomass adversely affect US wood pellet exports.

The third chapter of the thesis analyzes the potential of camelina as a renewable aviation fuel. Camelina has good oil content thus has the potential to supply the renewable aviation fuel. Camelina can be produced as a rotation crop and winter cover crop. This study considers camelina production as winter cover crop and analyzes the potential to supply renewable aviation fuel using a crop enterprise budget, the Environmental Policy Integrated Model (EPIC) and Partial Equilibrium Analysis (POLYSYS) models. This study calculates the cost of producing camelina, analysis the average yield variability in the US and simulates a national supply curve of camelina for different price scenarios. In the end, the supply of renewable aviation fuel from camelina is also generated at the national level.

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Chapter 1: Introduction

1.1 Introduction:

Energy use is growing all over the world due to both the growth and expansion of industries in countries. (Cheng, 2018). International Energy Outlook IEO, (2016) forecast found that over next three decade, energy use will continue to increases. Growing energy consumption will lead by outside of the Organization for Economic Cooperation and Development (OECD) member countries (mostly dominated by China and India). This forecast also shows there is potential growth in demand for renewable energy sources over the same period. Since increased energy use increases greenhouse gas emission, countries are focusing more on renewable energy consumption. (Cheng, 2018). Different countries have their own renewable policy goals. To achieve these goals countries are switching from fossil fuels to alternative renewable energy sources.

This study explores the potential of biomass in developing the renewable energy sector. The first essay of this thesis examines the export of wood pellets from the United States (US) to its top export markets and evaluates the factors affecting wood pellet exports. The second essay evaluates the energy crop Camelina's potential as a feedstock for the production of renewable aviation fuel in the US.

The first essay considers wood pellet trade as currently, the US is the largest producer and exporter of wood pellets (IEA, 2017). The main consumer of US produced wood pellets is through exports (IEA, 2017, EIA,2018). 63% of the wood pellet production of US is exported (IEA 2017). Wood pellet is a biomass to generate electricity and for residential heating. The use of wood pellets as an energy product is not new, they have been used for a long time by household and the small commercial heating. However, since 2008, there has been significant growth in the consumption and trade of wood pellets as biomass energy (Goetzl 2015, IEA, 2017). This growth has taken place as countries in the European Union, Japan, and Korea have adopted different policy initiative that incentivizes the use of biomass in energy production. (Goetzl 2015, IEA, 2017, ITA, 2016).

At present, the US maintains a dominant position in wood pellet exports and trade sector. However, the growth of this sector is dependent on the future growth of foreign markets (IEA, 2017). The first essay of this study analyzes the macroeconomic variables and renewable policies affecting US wood pellet export to its top markets, including UK, Belgium, France, Denmark, The Netherlands, Canada, Sweden, Japan, Germany, Italy, and South Korea (ITA,2016). A commodity specific gravity model is estimated to examine the factors affecting wood pellet export quantities by the US.

Camelina's supply potential as for the production of renewable aviation fuel in the US is analyzed in the second essay. There is demand for aviation fuel, as indicated by the Global Aviation Industry 's goal of achieving carbon-neutral growth by 2020 to reduce carbon emissions 50 percent by 2050 (IATA, 2009). Camelina is an oilseed crop from the mustard family that contains 35%-48% of oil content and as great potential to supply renewable aviation fuel (Grady & Nleya, 2010, Mupondwa et al., 2016).

Camelina has several benefits as an energy crop. These benefits are a high oil content, low input requirements with low herbicide and fertilizer costs. Camelina can also be produced as a rotation crop, in dryland, non-irrigated and no-till production system (Robinson, 1987, Grady & Nleya, 2010). Furthermore, the food versus fuel debate can be mitigated because camelina is produced when land is typically idle. (Reimer & Zheng, 2017). The second study evaluates the cost of Camelina production, its yield variability over the entire US and its supply potential as renewable aviation fuel using crop enterprise budgets, the Environmental Policy Integrated Model (EPIC) analysis, and The Policy System Analysis (POLYSYS) model.

References:

Cheng, J. (Ed.). (2018). Biomass to Renewable Energy Processes. Boca Raton: CRC Press.

(ITA). (2016). *2016 Top Markets Report Renewable Fuels Country Case Study: South Korea*.https://doi.org/10.5817/CP2013

Goetzl, A. (2015). *DEVELOPMENTS IN THE GLOBAL TRADE OF WOOD PELLETS*.

Grady, K., & Nleya, T. (2010). *Camelina Production*. *Agriculture*.

IATA. (2009). *A global approach to reducing aviation emissions*. Retrieved from http://www.iata.org/whatwedo/environment/Documents/global-approach-reducing-emissions.pdf

IEA. (2017). *Global Wood Pellet Industry and Trade Study 2017 Global Wood Pellet Industry and Trade Study 2017 Lead authors*.

IEO. (2016). *International Energy Outlook 2016*. *International Energy Outlook 2016* (Vol. 0484(2016)). https://doi.org/www.eia.gov/forecasts/ieo/pdf/0484(2016).pdf

Mupondwa, E., Li, X., Tabil, L., Falk, K., & Gugel, R. (2016). Technoeconomic analysis of camelina oil extraction as feedstock for biojet fuel in the Canadian Prairies. *Biomass and Bioenergy*, *95*, 221–234. https://doi.org/10.1016/j.biombioe.2016.10.014

Reimer, J. J., & Zheng, X. (2017). Economic analysis of an aviation bioenergy supply chain. *Renewable and Sustainable Energy Reviews*, *77*(April 2016), 945–954. https://doi.org/10.1016/j.rser.2016.12.036

Robinson, R. G. (1987). Camelina: a useful research crop and a potential oilseed crop. *Minnesota Ag. Expt. Stn. Bull. 579*, 2–12.

Chapter 2: Determining the Factors and Role of Renewable Policies Affecting US Wood Pellet Export- A Gravity Model Approach

Abstract

Wood pellets are biomass that can be used to generate electricity. Wood pellet use in electricity generation has rapidly increased since the 2008 because the European Union (EU) and other countries adopted new renewable energy policies that encouraged wood pellet use. The United States (US) is the world's largest producer and exporter of wood pellets. Thus, it is important to identify what factors and policies particularly drive wood pellet exports and what factors create a barriers in wood pellet trade. The objective of this study is to identify the factors and policies affecting wood pellet export by the US. A commodity-specific gravity model with importer fixed effect and both time and importer fixed effect is applied to determine the factors affecting US wood pellets exports. A monthly panel dataset of 11 countries buying wood pellet from the US is examined. The results suggested that renewable electricity production in importing countries, renewable electricity production as a proportion of importing countries Gross Domestic Product (GDP), per capita renewable electricity production in importing countries, US per capita GDP, and US renewable energy policy incenting domestic wood pellet production positively affect US wood pellet export. Importer's research and development policies supporting wood pellet production and trade barrier policies regulating biomass imports negatively affect US wood pellet exports.

2.1 Introduction:

Wood pellets are used for generating electricity and residential units. Wood pellets are produced from sawdust or other ground woody materials. Hence, wood pellets are a form of renewable biomass. International standard (ISO 17225-2) describes the product requirements for a wood pellet regarding moisture, energy density, particle size and shape (IEA, 2017). Wood pellets can be co-fired in coal-based power plants and directly fired in converted coal power plants for electricity generation which decrease greenhouse gas emissions. (IEA, 2017). Furthermore, wood pellets are extensively used for automatic stove and boilers as a solid biofuel in the residential heating sector (IEA, 2017). Additionally, wood pellets are also used for Combined Heat and Power Plant (CHP) in the industrial and commercial application and medium and large-scale thermal practices. (Goetzl 2015).

Wood pellets have a considerable practical advantage compared to wood chips or split wood in terms of handling, transport, energy density, and storage (Trømborg et al., 2013). Furthermore, because the moisture content is low, wood pellets have double the energy content of green wood. Additional benefits of burning wood pellets compared to raw wood are higher consistency, bulk density, and energy efficiency (Goetzl 2015).

The use of wood pellets as an energy product is not new, they have been used for a long time by household and the small commercial heating sector (Goetzl 2015). However, since 2008, there has been significant growth in the consumption and trade of wood pellets as biomass energy (Goetzl 2015, IEA, 2017). This growth has taken place since the European Union (EU) passed new renewable energy policies to reduce their greenhouse gas emissions (Goetzl 2015). The EU considers wood pellets as renewable energy sources to achieve their low emission targets. The EU considers wood pellets from a “sustainable forest” as carbon neutral. In the fiscal year, 2015-16 EU’s consumed 75% of the wood pellets produced globally while producing only 54% of total wood pellet supply (IEA, 2017). Therefore, local production of wood pellets is not sufficient to meet the demand, and global demand for wood pellets has increased rapidly (Goetzl 2015).

In contrast to the EU, the United States (US) is the largest producer and exporter of wood pellets (IEA, 2017). The main consumer of US produced wood pellets is through exports (IEA, 2017, EIA,2018). According to the International Energy Association (IEA) (2017), 63% of the wood pellet produced in the US are exported. The US is the largest exporter of wood pellets in the world market. On the other hand, the United Kingdom (UK) is the largest importer of wood pellets (IEO,2016 IEA,2017). Other large importers are Austria, Germany, Netherlands, Belgium, Denmark, Italy, and Sweden in Europe (ITA, 2016). Recently, in Asia, South Korea, and Japan are the emerging importers who mainly import from Vietnam and Canada (ITA, 2016, IEA, 2017). Reduced carbon emission targets are the driving force of increasing Asian demand (Goetzl 2015). In the Asian wood pellet market, the US faces lower feedstock prices and exchange rate difficulties (ITA, 2016).

Currently, the US has a very strong export performance in wood pellet trade sector. However, the growth of this sector is dependent on the future growth of foreign markets. In the absence of a foreign market, the growth of this industry will likely “decline or become stagnate”(IEA, 2017). From 2012 to 2015, US wood pellet exports increased by 150% (IEA, 2017). According to the International Trade Administration (ITA) (2016), US wood pellet exports were 5 billion Kilograms (KG) in 2015. It’s the closest competitor was Canada, whose exports reached 1.6 billion KG (ITA, 2016). The US wood pellet production and export play therefore an important role in world wood pellet trade and consumption. Identifying the drivers of the growth of wood pellet exports and the future potential is important to achieving a sustainable expansion of production and trade.

Renewable policies might affect wood pellet exports in different ways. Renewable policies like low carbon emission target policies drive the wood pellets exports growth in UK (Goetzl 2015). In contrast, renewable policies like Sustainability certification requirements could cause substantial decreases in US wood pellet exports in the Netherlands (IEA, 2017). The introduction of renewable policies that drive the domestic demand for wood pellets may adversely affect wood pellet export markets. In addition to policy, different macroeconomic variables and other factors affect the export market for wood pellets.

The objective of this study is to determine the factors affecting US wood pellet exports. It is hypothesized that wood pellet exports are impacted by the renewable electricity production of importing countries, importing countries renewable energy policies, US renewable energy policies, and exchange rate factors.

Different trade models can describe trade between countries. Classical economics focusses on absolute and comparative advantage of countries where new trade theory concentrates on the economics of scale, imperfect competition, and product differentiation. Since Adam Smith, several trade theories have been advanced that attempt to explain trade relations among countries (Leamer & Levinsohm J., 1995). According to Adam Smith, a state should produce a good in which they have absolute advantage and trade this good with other countries and get the benefits inherent in international trade. Later, Ricardo points out that the main weakness of Smith's theory was that, countries can have trade without having the absolute advantage to produce goods. Ricardo argued that a country would export those products in which they have a comparative advantage to produce and import to those that have a lesser comparative advantage. Ricardo's model, however, only considers labor as a factor of input (Ricardo, 1817; Binh, Duog, & Cuog, 2010).

The Heckscher-Ohlin (H-O) model extends Ricardo's model by including productive factors such as capital and land in addition to labor. The H-O model predicts that if a country produces a product using factors abundantly available, then that product will be exported; whereas if a country produces a product that uses scarce factors, they will import that product (Binh et al., 2010, Leamer & Levinsohm, 1995).

Since 1962, a gravity model of trade has been used to explain bilateral trade flows between two countries. This model can be used to find clear and robust empirical findings of trade where traditional theories cannot describe these factors that affect bilateral trade (Binh et al., 2010). This gravity model, formulated by Jan Tinbergen, has a strong theoretical foundation and has undergone significant development. Figure 2.1 gives an overview about the development of gravity model of trade. It has become one of the most successful empirical models to explain trade relationship (Salvatici, 2013). The gravity equation estimation approximates the bilateral trade flows of international trade. However, the literature using the gravity model for energy trade is limited compared to another different commodity trade literature.

This study divided the existing gravity model literature into three broad categories; 1. estimating policy impact on different trading commodities using gravity model, 2. evaluating energy trade using gravity model, and 3.example of commodity specific gravity model applications (Table 2.1).

The gravity model literature discussed in Table 2.1 focuses on the three areas of gravity literature. Grant & Lambert (2008), and Márquez-Ramos & Martinez-Gomez (2014), primarily focused on policy impact on international trade, thus include policy variables in the gravity model. Among them, Márquez-Ramos & Martinez-Gomez (2014), used monthly data to examine the Moroccan fruit vegetable trade on EU's market where Grant & Lambert (2008) evaluates the RTAs effect on agricultural and non-agricultural trade. Furthermore, Groba & Cao (2014) and Groba (2014) used a gravity model to evaluates the renewable energy trade while both studies include policy variable on the gravity model. Finally, Koo (1994), Jayasinghe et al. (2010), and De Matteis Maria, (2017) used commodity specific gravity model rather than the traditional gravity model of trade. These studies revised the gravity model with commodity demand in the importing countries.

ITA (2016), identifies the top markets for renewable export for the US and point out existing challenges, barriers, opportunities, and trends. According to this report, several numbers of European Union countries, Japan and South Korea are reducing carbon emission by substituting coal with biomass. The policy initiative of those countries drives the demand for wood pellets in the US. In 2015, the US captured 59% share of EU imports with 91% of these imports going to the UK According to ITA (2016), the top 11 markets of US wood pellets exports are UK, Belgium, France, Denmark, Netherlands, Canada, Sweden, Japan, Germany, Italy, and South Korea. This study divided all these eleven countries based on their market size and US share to that market. According to this division, UK and Belgium have a large market of a wood pellet export and the US has a large market share on that market where France, Denmark, and the Netherlands have a small market for wood pellet export, but the US has a large share on that market. Furthermore, Canada, Sweden, Japan, Germany, Italy, and South Korea has a large market of wood pellet export, but the US has a small share where Canada, Russia, and Vietnam have a large share on that above-market compare to the US.

Goetzl (2015) identified that the US produced wood pellet demand is partially domestic but mostly driven by the export market. In the US, the demand for wood pellets is driven by residential heating along with commercial heat and CHP applications. In the US, some coal power plants use wood pellets to co-fire with coal, but they mostly use wood chips rather than wood pellets. US wood pellet production is mainly concentrated in the southern part of the country where 98% of the wood pellet exports occurs.

Despite having high growth in trade and production of US wood pellets, the strong exchange rate is identified as one of the significant barriers to this export growth. The IEA,(2016) found that the exchange rate has a measurable effect on the import of wood pellets from non-EU countries. They concluded that US imports decline because of a strong US dollar and Russian import increase as the devaluation of the Russian currency took place.

The ITA, (2016) also identifies barriers for the US in Asian markets (mainly Japan and South Korea) are logistical cost, the price of feedstock and exchange rate. This study points out that, as most of the US exporters are based on Southeast leads to a high logistic cost for Asian markets.

Finally, the different literature suggests that policy perspectives play a crucial role in wood pellets trade and production. According to the IEA (2017), sustainability certification scheme is the primary challenge for a trade, while the ITA (2016) identifies the main barriers to wood pellet trade are "the absence of supportive policies or incentives in certain markets; national sustainability criteria that require documentation from the US forestry and agricultural supply chain …" (2016 ITA Renewable Fuels Top Markets Report, page 3). The same study concluded that a key strategy of exporters might be carefully monitoring the policy development of all exporting markets. Goetzl (2015) describes the two types of renewable policies where the first type increases the demand for wood pellets and the second type creates trade barriers. The first policy type may incorporate green certificates, feed-in tariffs, tax exemptions, loan guarantees, tax credits, and grants that incentivize the production of biomass (wood pellet) and drive the demand of wood pellets. In contrast, the second policy type may restrict trade or create trade barriers e.g., European Union Sustainability requirement that place a challenge to US trade of wood pellets. This study focuses on a set of renewable energy policies for both the importing countries and the US that incentivize or restrict wood pellet production and trade.

2.2 Conceptual Framework:

Tinbergen (1962) introduced his gravity model of trade that was influenced by Sir Isaac Newton's gravity model. His model assumes that trade between two countries is directly proportionate to the economy's size/ country size and inversely proportional to trade cost or transportation cost. The traditional form of the gravity model is following;

$$lnXij = ao + a1 * lnGDPi + a2 * lnGDPj + a3 * lnDij + a4 * lang + a5 * Pij + \varepsilon ij \tag{2.1}$$

Here Xij is the quantity of trade between country i to country j, GDPi and GDPj is the Gross Domestic Product (GDP) of exporting and importing countries, Dij is the distance between importing and exporting countries, lang is the dummy variable if both the countries share an official common language then it is 1, otherwise zero. Pij is the policy variable, which is a dummy variable and it can be any policy dummy variable that can affect the trade of two countries, for example, a free trade agreement between two countries.

However, the microeconomic foundation of this traditional gravity model is first provided by Anderson (1979). He used the constant elasticity of substitution (CES) framework to provide this foundation. In recent period Anderson & Wincoop (2003), Baier & Bergstrand, (2007) and Baldwin & Taglioni, (2006) provide subsequent reformation over Anderson (1979), work. Bergstrand (1985,1989 and 1990) introduce the supply side in the model and develop a relationship between trade theory and bilateral trade by including the price term. It suggests that the income of the importing country represents its demand for import while the income of exporting country represents its capacity for supply and distance reflects the transportation cost which transfers to the consumers of importing countries (Bergeijk & Brakman, 2010.). Anderson & Wincoop, (2003) argued that the traditional gravity equation in equation 1.1 does not have any theoretical foundation as it does not consider the prices. Anderson & Wincoop, (2003) provide the following form of gravity equation;

$$X_{ij} = \frac{Y_i Y_J}{Y_W} \left(\frac{t_{ij}}{P_i \; P_j}\right)^{1-\emptyset} \tag{2.2}$$

Here, X_{ij} is the trading quantity from country i to j, Yi, Yj is the income of two countries Yw is the world income and tij is the is the trade cost factor of i and j, where Pi, Pj is the respective exporter and importer price and φ is the elasticity of substation between all goods. Hence, ${P_i}^{1-\emptyset}$ and${P_j}^{1-\emptyset}$ are the exporter importer price indices which can be expressed as multilateral resistance term. (Bergeijk & Brakman, 2010) So according to Anderson & Wincoop (2003) trade between two countries does not only depend on their income and price but also "multilateral resistance term" which reflects a country's situation relative to the world economy (Bergeijk & Brakman, 2010) . However as the multilateral resistance term is largely unobservable, this multilateral resistance term can be controlled by using importer and exporter fixed effects in the cross-sectional model and by using country by time fixed effects in panel data model (Grant & Lambert 2008, Baier & Bergstrand 2007, Bergeijk & Brakman 2010).

2.3 Model Scenario and Estimation:

2.3.1 Model Scenario:

The traditional gravity model that is expressed in equation 1.1 can be represented as a general form of the following,

$$X_{ij} = K \frac{S_i^{\alpha} S_j^{\theta}}{TC_{ij}^{\gamma}}$$

Source: De Matteis Maria (2017) (2.3)

Where X is the amount of trade i to j, K, is the constant term, S is the economic size of countries, and TC is the trade cost where K is the constant term, α, θ, and γ are unknown parameters.

However, the gravity model can also include other variables that may affect the volume of trade. Some studies expanded gravity model by adding the exchange rate, tariff and nontariff measure, common language, common border, religion, and population, other variables. Koo(1994), revised the conventional gravity model to a commodity-specific model and examined factors that affecting meat trade. The standard gravity model assumes GDP as a proxy of economic size and distance as a proxy of trade cost where Koo (1994) showed that a country's farm income (GDP for the farm sector) could serve as a proxy of economic size. De Matteis Maria (2017) used a commodity-specific gravity model to examine the US DDGS trade and used the stock of cattle, beef and pork production, and beef and pork consumption as a proxy of economic size in three different model Scenarios. Jayasinghe et al. (2010) argued that when determining corn seed trade, total corn production is a better proxy for economic size than GDP. Hence, it is possible to develop a commodity-specific gravity model that can incorporate unique variables and policies that mainly affect a specific commodity trade (Koo 1994).

This current study develops a commodity-specific gravity model for US wood pellets trade. Two different models with three different model Scenarios will be explored. Table 2.2 represents two model, and it's three different Scenarios summary. From the Table 2.2, both models will estimate three Scenarios of wood pellet demand in importing countries. The rest of the thesis will denote Scenario 1 as RES production, Scenario 2 as RES/GDP, and Scenario 3 RES/. Renewable electricity production (RES Production) represents the quantity of renewable energy produced from solar, wind, biomass, and others but excluding hydro and nuclear.

The first Scenario assumes that renewable electricity production (RES production) as a proxy for economic size for wood pellet use/demand in the importing country. This is a conservative proxy as it only considers renewable electricity production for an importing country. A country might have higher renewable electricity production in gigawatt hours, but its renewable electricity production is minimal compared to income or population.

Thus, the second scenario assumes that the share of renewable electricity production in GDP (RES/GDP) for the importing country as a proxy of economic size for wood pellet use in that country. This demand variable includes the country's income as its share in GDP, so it is a broader definition of demand.

Finally, the third Scenario assumes, per capita, renewable electricity production (RES/POP) represents proxy of economic size for wood pellet use in importing countries. It is also a broader definition of demand as it connects population and its renewable electricity production. All three Scenarios also include the US demand for wood pellet by including the same variable form US side. For example, the US RES is used in the first scenario that represents US Scenario. Three Scenarios assume that wood pellets are used in renewable electricity production either in co-firing with coal and as a biomass-based residential or commercial heating system and in CHP plants.

Furthermore, several other variables and policies that may affect the US wood pellets exports are also included in this commodity specific gravity model. This model includes the US GDP, exchange rate, different renewable policies that affect wood pellet trade. There is no monthly wood pellet production data available prior to 2016 from US Energy Administration (EIA), so this study uses US GDP as a proxy of US capacity to export wood pellets thus assuming that as US GDP increases, wood pellet production increases. Van den Heuvel et al. (2011), argues that an exporter's GDP represents exporter capacity to export while importer's GDP represents its ability to import. In addition to that, the exchange rate is included in the model to see its impacts on wood pellet trade. This is because the exchange rate depreciation decreases the purchasing power for an importing country thus decrease the imports for that particular country while and appreciation increase the purchasing power thus the imports (De Matteis Maria, 2017).

Finally, this study considered a set of renewable energy policies that affect US wood pellet exports. Different renewable energy policies can affect the export in different ways. Groba and Cao (2014), divided the renewable energy policies into three broad categories; i.e., incentive tariffs, tax measures, and obligations, each of three was included as three policy dummies and allowed for evaluation of the impact on China's solar and WETC exports. Thus, this current study considers five policy dummies under three set of renewable energy policies. These policies include;

1. Renewable energy policies of US that increase wood pellet production thus increases in US wood pellet exports. This study uses a set of aggregate policies for the US that increase wood pellet production or give incentives for higher wood pellet production for the given period of January 2012-June 2017. These policies include a tax credit for biomass production, loan, grant or subsidies for biomass production plant, and research and development support policies for biomass production and renewable electricity production. Here, one aggregate policy variable is used to capture the US renewable energy policies in the model.
2. The second set of renewable policies are the renewable policies from importing countries that give the incentive to increase use of biomass in renewable electricity production and residential and commercial heating or boiler. In this regard, two policy

dummy variables are considered in the model. One variable is aggregate policy variable that includes any subsidies, feed-in tariffs, feed-in premium, loan or grant that is given for using biomass in a coal power plant, CHP plant, residential and commercial heating, or boiler system. This policy variable is named as targeted policy for biomass. Another policy variable includes all the general policy measures that give incentive to decrease the use of combustion fuel thus increase the use of biomass (wood pellet). These are mainly general poly for renewable electricity production rather than targeted for biomass-based production. This policy variable includes tax for using combustion fuel, renewable portfolio standards, quota policies for renewable use, trade in certificates for producing renewable electricity or any other obligations to use combustion fuel in electricity production.

3. The third set of policies are renewable energy policies from importing countries that might reduce wood pellet export of US. This set of policies include that policies which give the incentive to increase their domestic wood pellet production thus mitigate US wood pellet exports. Furthermore, this set of policies also include another set of barrier policy that strict the criteria for using biomass in power plants or biomass imports regulation policies; i.e., sustainability criteria. Finally, in this set of policy a country's strict target of certain percentage of domestic biomass production criteria is also included. In this set, this study uses two policy dummy variables; First policy dummy contains research and development policies that increase importing countries domestic wood pellet production and second policy variable include all the policies that create a barrier on the imports of biomass. In this second dummy this study included two policies. One policy is sustainability certification criteria of the Netherlands and

another one is domestic biomass production target by Canada. Table 2.3 represents the list of policy of importing countries and US that has been considered in the study for the given period.

This study assigns 1 when there is at least one policy for a given period for the policy type mentioned above and zero if there are no such policies.

In this study, the importer fixed effect is considered while estimating the gravity model to control for country-specific factors that may affect the trade flow. Thus, both distance and common language variable are dropped due to multicollinearity issues arises. (Sheldon Mishra, Pick & Thompson, 2013, Grant & Lambert 2008, De Matteis Maria, 2017, and Hatab, Romstad, & Huo, 2010).

Gravity Model Panel Scenarios with country fixed effects:

$$lnX_{i,j,t=i,USA,t} = \alpha_0 + \alpha_1 * lnGDP_{usa,t} + \alpha_2 * Z_{i,t}^{D} + \alpha_3 * Z_{USA,t}^{E} + \alpha_4 * lnEX_{i,t} + \alpha_5 * P_{usa,t} + \alpha_5 * P_{i,t} + \alpha_6 * bP_{i,t} + \delta_i + \varepsilon_{i,j,t} \quad (2.4)$$

Where, X_{ijt} is the wood pellet exports in quantity from the US to importing countries for a given period, $GDP_{usa,t}$ is the US per capita GDP which represents US capacity to export, $Z_{i,t}^{D}$ represents the market size for US wood pellet export in importing countries the variables defined three Scenario above, $Z_{USA,t}^{E}$ represents the market size of wood pellet use in the US using a variable in three Scenario above, $EX_{i,t}$ is exchange rate of US currency to the importing country's currency, $P_{usa,\,t}$ are the policies of the US that give incentive to wood pellet production, $P_{i,t}$ is the policy variables of importing countries that give incentive to use wood pellet thus increse wood pellet imports (two policy dummy for $P_{i,t}$), and $b_{Pi,t}$ is the policy variables that create barrier in wood pellet exports in importing countries (another two policy dummy), δ_i is the importing country fixed effect and $\varepsilon_{i,j,t}$ is error term.

This study also estimates both time and country fixed effect to control for time-specific and country-specific issues.

$$lnX_{i,j,t=i,USA,t} = \alpha_0 + \alpha_1 * lnGDP_{usa,t} + \alpha_2 * Z^{D}_{i,t} + \alpha_3 * Z^{E}_{USA,t} + \alpha_4 * lnEX_{i,t} + \alpha_5 * P_{usa,t} + \alpha_5 * P_{i,t} + \alpha_6 * bP_{i,t} + \delta_i + \mu_t + \varepsilon_{i,j,t} \qquad (2.5)$$

Here, μ_t represents the time fixed effects. Equation 2.5 also control for time specific unobserved heterogeneity along with country specific unobserved heterogeneity. (Grant & Lambert 2008). Thus, as presented in Table 2.2, this study estimates the two models described in equation 2.4 and equation 2.5 for all three Scenarios discussed above.

2.3.2 Estimation:

The equation 2.4 and 2.5 is estimated through log-log OLS estimation with bootstrap estimation technique. It is essential to choose an appropriate number of bootstrap replication while doing bootstrap for the data. This study used Poi (2004) method to select the appropriate number of bootstrap replications. Each Scenario and each model are bootstrapped with an optimum number of bootstrap replications through STATA bootstrap command suggested by Poi (2004).

The dataset of this study it is an unbalanced panel with a gap in the panel. Each of the importing countries reports their imported quantity of wood pellet from the US in a monthly basis. In this case, some month trade is not published by those importing countries, this is because the trade does not occur on those month or maybe the country did not report that trade. Hence, we have a gap in months, but there are no zeros in the data set. While estimating the gravity model one of the most critical concern is dependent variable contains zero values, which will create an estimation inconsistency in OLS estimation, as a log of zeros is not defined (Silva & Tenreyro 2006, Westerlund & Wilhelmsson 2011, Groba & Cao 2014). Hence, there will be a loss of information if OLS estimation is used in the presence of zero trade. However, the dataset of the current study does not have any zero-pellet trade, so bias in OLS estimation caused by zero values are not a concern in this study.

Another common estimation issue is unobserved heterogeneity from the country and time-specific factors which is taken care off by employing importer fixed effects in equation 2.4 and both importer and time specific fixed effects in equation 2.5.

2.4 Data:

Data on monthly US wood pellet export quantity from January 2012-September 2017 was obtained from UN COMTRADE database. This study estimated gravity estimation for a sample of 11 countries from UN COMTRADE data. ITA (2016), identify these eleven countries as top potential markets for US wood pellet export. These countries are U.K, Belgium, France, Denmark, Netherlands, Canada, Sweden, Japan, Germany, Italy, and South Korea. Each importing countries reported that quantity of wood pellet imports to UN COMTRADE in each month where the unit is net weight kilogram. UN COMTRADE started collecting the data for wood pellet as a separate HS Commodity (HS440131) from the beginning of 2012. Until 2012, the wood pellet was a part of other wood related trade commodity that contains wood chips, and other wood particles that used as fuel under HS440130 (Goetzl 2015). Hence, this current study collected data from UN COMTRADE as HS440131 commodity from January 2012 for all sample countries.

Monthly exchange rate data is gathered from the IMF database. This study considered monthly US dollar to other currency exchange rate at the end of period average. The data on renewable electricity production from solar wind, biomass, and other excluding hydro and nuclear in gigawatt is collected from the IEA monthly electricity database.

The data on GDP per capita in 2010 constant dollar, GDP in 2010 constant dollar, and population for sample countries with the US is collected from the World Bank database. The renewable electricity production (from solar, wind, biomass, and others) as a share of GDP and per capita renewable electricity production (from solar, wind, biomass, and others) for each month for all sample countries and the US is obtained through hand calculation of author. Furthermore, the 2017 GDP, per capita GDP and the population are also forecasted data point which is calculated through last year growth rate calculations.

All the policy variables are collected from IEA/IRENA joint policy and measure database under global renewable energy webpage. In case of US total ten policies was considered that directly give incentive to biomass (wood pellet) use and production. For all eleven sample countries, approximately 60 renewable policies were considered among approximately 300 policies for the given period. EU's sustainability criteria on biomass trade and Netherlands' Sustainability requirements on biomass trade was collected through their official policy documentation.

2.5 Result:

The results of the two models with each Scenario are given in Table 2.5 and Table 2.6 Table 2.5 represents the three Scenarios result with a country-specific fixed effect where Table 2.6 represents three Scenarios result in both country-specific and time fixed effect. Both tables contain a bootstrap standard error of every parameter in parenthesis. The parameter estimation for all explanatory variable for both model in all three Scenarios are very similar. Sign and level of significance are same for all variables in all three estimation for both models.

In Scenario 1 (RES production), renewable electricity production (from solar, wind, biomass, and other) as a proxy of economic size of wood pellet use in importing country is positive and significant at 1% level in both importer fixed effect model and importer and time fixed effect model. The result shows that 1% increase in renewable electricity production will increase wood pellet export by 0.802% in importer fixed effect model and 0.807% in both importer and time fixed effect model.

In Scenario 2 (RES/GDP), the importer shares of renewable electricity production in GDP which as a proxy of economic size for wood pellet use in importing country has a significant and positive effect at 1% level for both models. When the importer effect is fixed, a 1% increase in importer share of renewable electricity production will increase the wood pellet export by 0.82%. In addition to that, when both time and importer effect is fixed, a 1% increase in that demand variable will increase wood pellet export by 0.84% approximately.

In Scenario 3 (RES/POP), the importer's per capita renewable electricity production represents the economic size of a wood pellet use in importing country. The variable is significant at the 1% level in both fixed effect models. In importer's fixed effect model, a 1% increase in per capita renewable electricity production for importing country will increase US wood pellet exports by 0.79%. Moreover, a 1% increase in per capita renewable electricity production will increase US wood pellet exports by 0.796% according to both models.

The variables that represent domestic economic size of wood pellet use in RES Production, RES/GDP and RES/POPN scenarios comes insignificant in both models. Hence, US renewable electricity production, US renewable electricity production as a proportion in GDP and US per capita renewable electricity production all are insignificant in both models and unable to explain US wood pellet export. Therefore, this may suggest US domestic demand could meet without affecting the supply of wood pellet export.

Per capita, US GDP is positively significant at 10% level for all three Scenarios in both models. A one percent increase in US GDP will increase wood pellet exports within a range of between 19.85%-22.92%. So, according to Table 2.5 and 2.6, when US GDP will rise by 1%, US wood pellet export may increase in between 19.85%-22.92%.

Furthermore, US renewable policy is positively significant at 5% level for all three Scenarios in both models. Hence, the presence of US renewable policy may increase the US wood pellet export between 303.49%-313.71% in all three Scenarios for both models. This is because the presence of US renewable policies is directly given incentive to wood pellet production in the US thus the export of wood pellets increases when this production of wood pellet increases.

On the other hand, importing countries research and development policy for their wood pellet production is negative and significant at the 10% level in both models for all three Scenarios. The presence of research and development policy in importing countries may decline the wood pellet export of US, and the range of decrease is between 171.83% - 174.56%. This is because, when an importing country has a research and development policy for biomass production, it will give emphasize on their domestic production instead of importing from other countries.

In addition to that, the barrier policies, are negatively significant at 1% level for all three Scenarios in both models. Presence of barrier policy may decrease the wood pellet export of US by 1594.55% to 1791.58%, and this range is calculated from all three Scenario and their two model parameters.

In all three Scenarios and two fixed effect model, exchange rate, importer direct financial incentive renewable policy and indirect policy measures comes insignificant.

2.6 Conclusion:

The elements that affect US wood pellet exports used for renewable electricity generation in the importing countries along with the US are evaluated. Understanding the elements of wood pellet market is crucial since wood pellet production in the US is dominated by export demand. This wood pellet demand is growing quickly and facing different policy challenges.

This study examines the US wood pellet export market through a set of commodity specific gravity models. The panel dataset of this study consists of 11 importing countries monthly data from January 2012 to September 2017. The results suggested that the following variables will impact wood pellet exports:

1. US GDP,

2. demand for wood pellets in importing countries,

3. US renewable energy policy which gives incentive to US wood pellet production,

4. importer's research and development policy for their wood pellet production and

5. barrier policy or the trade regulation policy for biomass.

Among these factors, the demand for wood pellets in the importing country and trade regulation policies that affect the wood pellet export has a significant impact on US wood pellet export. The demand for wood pellets in importing countries is the amount of renewable electricity production (from solar, wind, biomass, and others) in Gigawatt/hour, the share of renewable electricity production in GDP, and per capita renewable electricity production.

The results indicate that importer's domestic renewable policies which give incentive to more biomass use; both targeted policies for biomass and general policies for renewable electricity production are insignificant or unable to affect the US export of wood pellet. On the other hand, importer policies that will give incentive to domestic wood pellet production that will decline the US export, while the US renewable policy that provides an incentive to US wood pellet production increase the US wood pellet export. Hence, the domestic renewable policy may push the demand for biomass in their country for renewable electricity production, but these policies are unable to create any significant effect on its import from the United States. These countries may import from other countries rather US. This study is only focusing on wood pellet export from US, a broader picture of whole wood pellet trade all over the world may give a clear image of compitation between exporting and importing countries. This is one limititation of this study and left for future reaserch.

On the other hand, the trade regulation policies have a vast level of adverse impact on the trade. This study is used US GDP as a proxy for US wood pellet production or its capacity to supply the export. The result showed that an increase in US GDP increase the capacity to supply the export thus increase the wood pellet export in importing countries. Direct data on US wood pellet production could be used in future studies to provide a better US capacity to supply estimation. This may consider as another limitation of the study and left for future research.

References:

(ITA). (2016). *2016 Top Markets Report Renewable Fuels Country Case Study: South Korea*. https://doi.org/10.5817/CP2013

Agostino, M. R., Cardamone, P., Matter, D. A., & Aiello, F. (n.d.). Analysing the Impact of Trade Preferences in Gravity Models . Does Aggregation Matter ?

Anderson, J. E., & Wincoop, E. van. (2003). Gravity with Gravitas : A Soiution to the Border Puzzie. *The American Economic Review*, *93*(1), 170–192. https://doi.org/10.1257/000282803321455214

Baier, S. L., & Bergstrand, J. H. (2007). Do free trade agreements actually increase members' international trade? *Journal of International Economics*, *71*(1), 72–95. https://doi.org/10.1016/j.jinteco.2006.02.005

Baldwin, R., & Taglioni, D. (2006). Gravity for Dummies and Dummies for Gravity Equations. *Nber Working Paper Series*, 1–29. https://doi.org/10.1017/CBO9781107415324.004

Bergeijk, P. A. G. Van, & Brakman, S. (n.d.). Introduction. In P. A. G. van Bergeijk & S. Brakman (Eds.), *The Gravity Model in International Trade* (pp. 1–26). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511762109.001

Binh, D. T. T., Duog, N. V., & Cuog, H. M. (2010). Applying Gravity Model to Analyze Trade Activities of Vietnam. *Discussion Papers on Economics, University of Vietnam*.

De Matteis Maria et al. (2017). Analyzing the Determinants of US. Distillers' Dried Grains with Solubles Exports (Vol. 11, pp. 109–117). https://doi.org/10.13748/j.cnki.issn1007-7693.2014.04.012

E., A. J. (1979). a Theoretical Foundation for. *The American Economic Review*, *69*(1), 106–116.

Goetzl, A. (2015). DEVELOPMENTS IN THE GLOBAL TRADE OF WOOD PELLETS.

Groba, F. (2014). Determinants of trade with solar energy technology components: evidence on the porter hypothesis? *Applied Economics*, *46*(5), 503–526. https://doi.org/10.1080/00036846.2013.857005

Groba, F., & Cao, J. (2014). Chinese Renewable Energy Technology Exports: The Role of Policy, Innovation and Markets. *Environmental and Resource Economics*, *60*(2), 243–283. https://doi.org/10.1007/s10640-014-9766-z

Hatab, A. A., Romstad, E., & Huo, X. (2010). Determinants of Egyptian Agricultural Exports: A Gravity Model Approach. *Modern Economy*, *01*(03), 134–143. https://doi.org/10.4236/me.2010.13015

IEA. (2016). *The European wood pellet market for small- scale heating The European wood pellet market for small-scale heating*.

IEA. (2017). *Global Wood Pellet Industry and Trade Study 2017 Global Wood Pellet Industry and Trade Study 2017 Lead authors*.

IEO. (2016). *International Energy Outlook 2016*. *International Energy Outlook 2016* (Vol. 0484(2016)). https://doi.org/www.eia.gov/forecasts/ieo/pdf/0484(2016).pdf

Jarreau, J. (2015). Determinants of trade policy: Insights from a structural gravity model. *World Bank Economic Review*, *29*(July), S155–S163. https://doi.org/10.1093/wber/lhv024

Jayasinghe, S., Beghin, J. C., & Moschini, G. (2010). Determinants of world demand for US. corn seeds: The role of trade costs. *American Journal of Agricultural Economics*, *92*(4), 999–1010. https://doi.org/10.1093/ajae/aaq056

Koo, W. (1994). A gravity model analysis of meat trade policies. *Agricultural Economics*, *10*(1), 81–88. https://doi.org/10.1016/0169-5150(94)90042-6

Lambert, D. M., & Grant, J. H. (2008). Do regional trade agreements increase members' agricultural trade? *American Journal of Agricultural Economics*, *90*(3), 765–782. https://doi.org/10.1111/j.1467-8276.2008.01134.x

Leamer, E. E., & Levinsohm J. (1995). *International Trade Theory: The Evidence*. *NBER Working Paper*.

Márquez-ramos, L., & Martinez-gomez, V. (2014). A gravity assessment of Moroccan F & V monthly exports to EU countries : The effect of trade preferences revisited.

Poi, B. (2004). From the help desk: Some bootstrapping techniques. *The Stata Journal*, *4*(3), 312--328. https://doi.org/The Stata Journal

Ricardo, David, 1772-1823. (1817). On the principles of political economy and taxation. London :John Murray,

Salvatici, L. (2013). *The gravity model in international trade*. *The trade impact of European Union preferential policies*. https://doi.org/10.1007/978-3-642-16564-1

Sheldon, I., Mishra, S. K., Pick, D., & Thompson, S. R. (2013). Exchange rate uncertainty and US bilateral fresh fruit and fresh vegetable trade: An application of the gravity model. *Applied Economics*, *45*(15), 2067–2082. https://doi.org/10.1080/00036846.2011.650330

Silva, J. M. C. S., & Tenreyro, S. (2006). the Log of Gravity, *88*(November), 641–658. Retrieved from https://www.mitpressjournals.org/doi/pdf/10.1162/rest.88.4.641

Trømborg, E., Ranta, T., Schweinle, J., Solberg, B., Skjevrak, G., & Tiffany, D. G. (2013). Economic sustainability for wood pellets production - Acomparative study between Finland, Germany, Norway, Sweden and the US. *Biomass and Bioenergy*, *57*, 68–77. https://doi.org/10.1016/j.biombioe.2013.01.030

van den Heuvel, F. P., de Langen, P. W., van Donselaar, K. H., & Fransoo, J. C. (2011). Identification of Employment Concentration and Specialization Areas : Theory and Application. *Beta Working Paper*, *354*(August), 26p. https://doi.org/10.1002/agr

Wang, X., & Badman, R. P. (2007). A Multifaceted Panel Data Gravity Model Analysis of Peru ' s Foreign Trade, 1–16.

Westerlund, J., & Wilhelmsson, F. (2011). Estimating the gravity model without gravity using panel data. *Applied Economics*, *43*(6), 641–649. https://doi.org/10.1080/00036840802599784

Appendix:

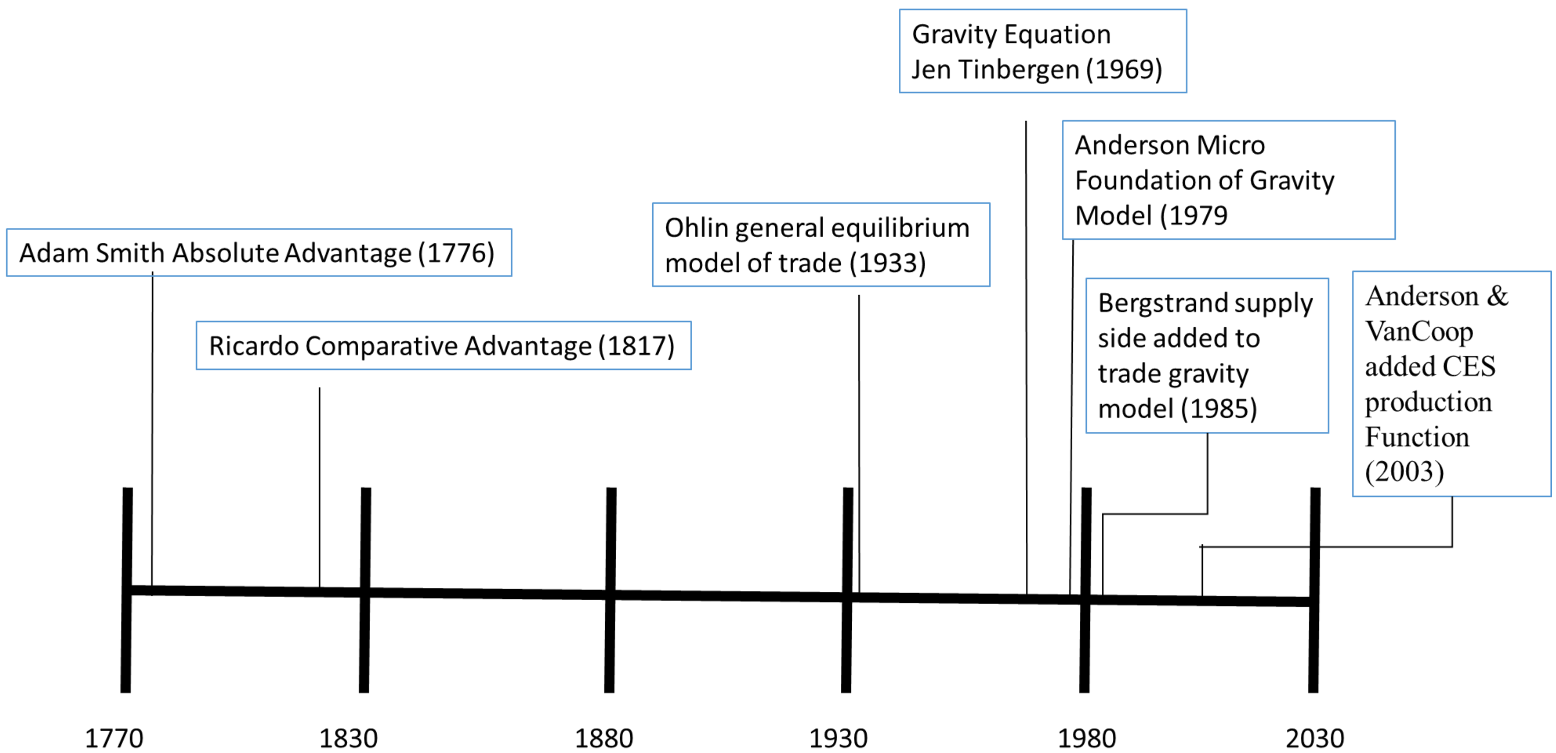

Figure 2. 1: Development of the Gravity Trade Model

Table 2. 1: Different Estimation Technique for Gravity Model, Findings, and Critiques in Literature

Authors	Type of Gravity Model	Brief Description	Limitations/Critic
(Grant &Lambert 2008)	Log Level Gravity Equation with Panel Data which considering different fixed effects (F.E) model. i.e., no time or country F.E, time F.E but no country F.E, time, and bilateral pair F.E, bilateral pair, and country by time F.E	This study investigates the Regional Trade Agreement (RTA) effect on agricultural and non-agricultural trade. The results suggested that RTAs has a higher impact on agricultural trade compare to non-agricultural trade as agricultural trades are always subject to a high level of trade restrictions. Furthermore, this study also found that the length of implementations (phase-in of RTAs) and specific agreement may cause different effects on RTAs on trade. For example, the cumulative impact on agricultural trade will increase by 149% after 12 years of phase-in of RTAs which is more than double the effect while the RTAs phase-in is not considered.	Differentiated RTAs effected on agricultural and non-agricultural trade and showed that how the difference in phase in periods of RTAs create different cumulative effects on trade. Finally, the effects of RTAs and their phase-in periods are different depends on specific agreement types. However, the effects of RTAs on specific commodities are not considered.
(Westerlund & Wilhelmsson, 2011)	Poison Maximum Estimation with standard bootstrap error	This study examined the EU's 1995 enlargement over trade. The result found that when EUs has new member countries its trade diversion effect is more significant than the trade creation effect. This study mainly argued that log-linear fixed effect LS estimator is biased estimator compare to Poison ML estimator. With Monte Carlo Estimation technique the study showed that fixed effect log liner LS estimator is very poor, where ML estimator is good estimator with downward biased in standard error. Thus, they used bootstrapped standard error with non- linear poison ML estimator to correct the downward bias of normal standard error.	The model is directly estimated form non -linear form Poison ML estimator with bootstrapped SE. This study argues that with Monte Carlo Estimation log-linear fixed effect OLS estimator are biased estimator with an example of EUs 1995 enlargement of trade.

Table 2.1: Continued

Authors	Type of Gravity Model	Brief Description	Limitations/Critic
(Groba & Cao 2014),	Poisson-Pseudo-Maximum-Likelihood (PPML) and Negative Binomial Estimation technique in Gravity Model with annual panel data.	Examine the effect of GDP per capita, country size, import tariff, distance, market size (which is calculated by the amount of electricity generated by solar PV and wind energy), renewable policies (that encourage renewable use in electricity generation), and R & D appropriation growth, bilateral knowledge transfer and indigenous innovation on solar PV and wind energy components (WETC) export of China. Key findings of the study are high income, renewable policy scheme, large renewable market size, and Chinese providential government research and development appropriation have a positive impact on exports. Trade cost has a negative effect where bilateral knowledge transfer and indigenous innovation does not have a significant impact.	Differentiated between incentive tariff, obligation, and tax measures among renewable supporting policy scheme. However, only considered the selected type of policy and neglected the policy mix.
(Groba 2014)	Poison Maximum Likelihood estimation in a gravity model with annual panel data.	Assesses the role of renewable policy and trade barriers to solar energy technology components (SETCs) for 21 OECD countries to 118 importing countries. Examine the Porter and the lead-market hypotheses which suggests that early adoption of renewable policy will give a comparative advantage to export. Results suggested that Europe has the rapidly growing market and dominates the SETCs trade and found the evidence in favor of Porter and the lead-market hypotheses. Findings also suggested that importer regulatory policies and import tariffs determine SETCs export.	Differentiated between demand pull (electricity generation policy) technology push (support innovation) policy and specifically examine their effect
(Márquez-ramos & Martinez-gomez, 2014)	Country-specific fixed effect estimation in gravity model with monthly data	Examine the preferential trade agreement policy on Moroccan fruit and vegetable exports export to European Union countries. Result suggests that negotiating trade preference has a positive impact on fruit and vegetable exports.	Constructed three indicators to study a different type of preference and trade policy and comprise them to the gravity model.
(Koo 1994)	Commodity-specific gravity model with cross-section and time series data.	Evaluate the meat trade and found that trade policies and subsidies used by importing, exporting countries, livestock production of countries and distance are critical to determining the meat trade. In contrast import quota and hoof and mouth disease of beef decline the trade. The long-term agreement increases the international trade at the highest level.	Revised the gravity model to a commodity-specific gravity model for meat and used farm income as a proxy of economic size rather than GDP.

Table 2.1: Continued

Authors	Type of Gravity Model	Brief Description	Limitations/Critic
(Jayasinghe et al. 2010)	Commodity-specific gravity model with Maximum Likelihood of Sample Selection Model	Evaluates the factors of corn seed trade and found that all type of trade cost significantly decreases US corn seed exports.	Construct a commodity-specific gravity model and showed that, total corn production is a better proxy than GDP for importing country's economic size.
(De Matteis Maria 2017)	Poison Maximum likelihood estimation in commodity-specific gravity model.	Examine the factors affect US DDGS exports to 29 countries from 2000-2013. Findings suggested that US ethanol production and meat production of importing country has a positive impact on US DDGS export where demand for DDGS is estimated through the meat production of importing countries. Furthermore, tariff negatively impacts the DDGS export.	Constructed a baseline outlook for top six importing countries of US DDGS exports till 2020 and build a scenario analysis to examine DDGS export in a different scenario (High and low meat production scenario for different countries).

Table 2. 2 : Table for Model Scenario Estimation

Type of Model	Scenario 1	Scenario 2	Scenario 3	Fixed Effect
Log-Log Gravity Model with country fixed effect	Importer Renewable Electricity Production is representing the demand for wood pellet import	Importer Share of Renewable Electricity production in GDP is representing the demand for wood pellet import	Importer Per Capita Renewable Electricity Production is representing the demand for wood pellet import	Yes, Country Fixed Effect
Log-Log Gravity Model with both country fixed effect and time fixed effect	Importer Renewable Electricity Production is representing the demand for wood pellet import	Importer Share of Renewable Electricity production in GDP is representing the demand for wood pellet import	Importer Per Capita Renewable Electricity Production is representing the demand for wood pellet import	Yes, both Country and Time Fixed Effect

Table 2. 3: Renewable Policy Collection

Policy Name	Countries	Policy Criteria	Date Effective	Comment
Feed-in premium for renewable energy sources other than photovoltaic	Italy	Importer biomass targeted policy included in second set of policy. Fiscal incentive for biomass plant	June 2016	Included in importer's targeted policy dummy for biomass
Renewable Energy for Heating and Cooling and Small Interventions Increasing Energy Efficiency Support Scheme (2.0)	Italy	Importer biomass targeted policy included in second set of policy. Fiscal incentive for heating.	May30th,2016	Included in importer's targeted policy dummy for biomass
Feed-in premium for renewable energy sources other than photovoltaic	Italy	Importer biomass targeted policy included in second set of policy. Fiscal incentive for biomass plant.	July 6th, 2012-May 30th 2016	Included in importer's targeted policy dummy for biomass
Renewable Energy for Heating and Cooling and Small Interventions Increasing Energy Efficiency Support Scheme (1.0)	Italy	Importer biomass targeted policy included in second set of policy. Fiscal incentive for heating.	2012-2016	Included in importer's targeted policy dummy for biomass
Feed in Tariff Policy of France	France	Direct fiscal incentive included in second set of policy under targeted policy of biomass. Policy for biomass power-plant >500kw.	2016-onwards	Included in importer's targeted policy dummy for biomass
Energy Transition Act	France	Importer general renewable policy not exclusively targeted for biomass, included in second set of policy.	July 2015-Onwards	Included in importer indirect policy dummy.
Renewable Energy Target	France	Renewable electricity generation targets for 2018 and 2023 for each source. i.e. solar, biomass, wind, etc.	April 24th, 2016 to onwards.	Included in importer indirect policy
Energy Policy of 2030 in Quebec[1]	Canada	Policy target of producing 50% more biomass by the year 2030. Target for high domestic production	2016-onwards	Included in barrier policy and research and development policy dummy.

[1] This policy for Canada has provisions for both research and development support for biomass production and a domestic wood pellet production targets that create barrier to import of wood pellet. Thus, policy is included in two policy dummies.

Table 2.3 continued

Policy Name	Countries	Policy Criteria	Date Effective	Comment
Community Feed-in-Tariff (COMFIT) of Nova Scotia	Canada	Importer's targeted policy for biomass production. Fiscal incentive includes feed in tariffs/premiums for biomass-based RES	2011-onwards	Included in importers target policy for biomass production dummy.
Subsidy scheme for households supporting energy saving measures and housing refurbishment	Belgium	Importer targeted policy for biomass. Fiscal incentive policy includes grant and subsidies for biomass plant.	2015-onwards	Included in importers target policy for biomass production dummy.
Energy Fund Grants for Small-Scale Heat Generation - Wallonia	Belgium	Importer targeted policy for biomass. Fiscal incentive policy includes grant and subsidies for biomass plant.	2005-2015	Included in importers target policy for biomass production dummy.
The Contract for Difference (CFD) for renewable energy is a key mechanism of Electricity Market Reform.	UK	Importer's targeted policy for biomass production. Fiscal incentive includes feed in tariffs/premiums for biomass-based RES.	October 2014-onwards.	Include in importer's targeted policy for biomass.
Renewable Heat Incentive (RHI) for domestic and non-domestic generators	UK	Importer's targeted policy for biomass production. Fiscal incentive includes feed in tariffs/premiums for biomass-based heating.	2011-onwards (updated in 2015)	Include in importer's targeted policy for biomass.
Feed-in Tariffs for renewable electricity for PV and non-PV technologies	UK	Importer's targeted policy for biomass production. Fiscal incentive includes feed in tariffs/premiums for all RES production include biomass-based CHP and others.	2010-onewards (updated in 2015)	Include in importer's targeted policy for biomass.
2014 Amendment of Renewable Energy Act	Germany	Importer's targeted policy for biomass production. Fiscal incentive includes feed in tariffs/premiums.	2014-Onwards	Include in importer's targeted policy for biomass.
2012 Amendment of Renewable Energy Act	Germany	Importer's targeted policy for biomass production. Fiscal incentive includes feed in tariffs/premiums.	2012-2014	Include in importer's targeted policy for biomass.
Energy Strategy 2050	Denmark	Importer's general renewable electricity policy for RES production	2010-onwards	Include in general renewable policy for RES production dummy.
Sustainability Certification Criteria[2]	The Netherlands	The Netherlands's exclusive policy about criteria about biomass (includes some criteria that reduce US wood pellet export)	April 2015-onwards	Include in barrier policy dummy

[2] Criteria includes forest size, forest environment, carbon storage of forest and wood pellet quality etc.

Table 2.3 Continued

Policy Name	Countries	Policy Criteria	Date Effective	Comment
Denmark National Renewable Energy Action Plan (NREAP)	Denmark	Importer's targeted policy for biomass production which includes fiscal support.	2010-onwards	Include in importer's targeted policy for biomass.
Feed-in Premium Program SDE	The Netherlands	Importer's targeted policy for biomass production which includes fiscal support.	2011-onwards (updated in 2016)	Include in importer's targeted policy for biomass.
National Renewable Energy Action Plan (NREAP)	The Netherlands	Importer's general renewable electricity policy for RES production, mainly focus on strategic planning for RES production and development.	2010-onwards	Include in general renewable policy for RES production dummy.
National Renewable Energy Action Plan (NREAP)	Sweden	Importer's general renewable electricity production action plan mainly focus on strategic planning for RES production and development.	2010-onwards	Include in general renewable policy for RES production dummy.
Feed in Tariff for Electricity from Renewable Energy Sources	Japan	Importer's targeted policy for biomass production which includes fiscal support.	July 2012-onwards.	Include in importer's targeted policy for biomass.
Renewable Portfolio Standard	Japan	Renewable portfolio standard which is included in importer general policy for RES production not targeted for biomass.	2003-June 30th 2012	Include in general renewable policy for RES production dummy.
Renewable Energy Certificate of Korea	Korea	Importer's general renewable electricity production action plan that include renewable certificate program.	2012-onwards.	Include in general renewable policy for RES production dummy.
American Recovery and Reinvestment Act of 2009: Tax-Based Provisions	US	US targeted policy for biomass that include fiscal incentives i.e grant and tax reliefs.	2009-2016	Included in policy dummy for US
Bureau of Land Management Renewable Energy Resources	US	US targeted policy for biomass that include fiscal incentives i.e grant and subsidies. Public land site is giving to renewable energy production.	2009-onwards	Included in policy dummy for US
Community Renewable Energy Deployment Grants	US	US targeted policy for biomass that include fiscal incentives i.e grant and subsidies. This support was given to small renewable plant.	2007-2014	Included in policy dummy for US
Energy Independence and Security Act of 2007	US	US regulatory instrument based and strategic planning-based policy support.	2008-onwards	Included in policy dummy for US
Section 1703/1705 Loan Guarantee Program	US	Loan for small renewable production project-biomass production	2006-onwards	Include policy dummy for US

Table 2. 4: Summary Statistics of Data

Variable	Unit	Mean	Standard Deviation	Minimum	Maximum
Wood Pellet Trade Quantity	Kilogram	41,700,000	90,600,000	1	49,800,0000
Renewable Electricity Production of Importing Country	Gigawatt/Hour	2658.52	2667.55	185	13946
Renewable Electricity Production of US	Gigawatt/Hour	19856.48	4982.42	10645	34521.05
US Per Capita GDP	2010 constant dollar	51053.73	1179.917	49497.59	52775.1
Per Capita Renewable Electricity production of Importing Countries	Gigawatt/per person	0.0062	0.005	0.00037	0.036
Per Capita Renewable Electricity Production of U. S	Gigawatt/per person	0.0063	0.0015	0.0034	0.0106
Share of Renewable Electricity Production in GDP for Importing Countries	Gigawatt/per dollar	0.00000000136	0.000000000910	0.000000000100	0.000000006
Share of Renewable Electricity Production in GDP for U. S	Gigawatt/per dollar	0.000000001210	0.000000000269	0.000000000685	0.00000000201
Exchange Rate	US$ to Local Currency	46.32	198.66	0.59	1199.1

Table 2. 5: OLS Estimation of Gravity model with Bootstrap Standard Error with importer fixed effect [Dependent Variable Ln (wood pellets quantity of imports)]

Variable	Scenario 1	Scenario 2	Scenario 3
Intercept	-233.12* (130.06)	-192.97 (132.73)	-214.91* (126.30)
Ln (Importer's Renewable Electricity Production)	0.802***((0.300)		
Ln (US Renewable Electricity Production	1.03 (0.789)		
Ln (US GDP Per Capita)	21.68*(12.11)	22.92* (11.92)	22.24* (11.58)
Ln (exchange rate)	0.109 (0.159)	0.124 (0.170)	0.111(0.162)
US Renewable Policy	1.42** (0.595)	1.44** (0.604)	1.42**(0.593)
Importer's Targeted Renewable Policy for biomass	-0.381 (0.653)	-0.274(0.682)	-0.298 (0.687)
Importer's General Policy for RES Production (obligations, quota RPS and others)	0.339(0.653)	0.294(.906)	0.393(0.915)
Importer's Research and Development Policy for Biomass Production	-1.00* (0.545)	-0.999*(0.543)	-1.01*(0.561)
Barrier Policy	-2.94***(0.718)	-2.94***(0.704)	-2.93***(0.728)
Ln (Importer Share of Renewable Electricity Production in GDP)		0.820***(0.284)	
Ln (US Share of Renewable Electricity) Production in GDP		1.05 (0.797)	
Ln (Importer's Per capita Renewable Electricity Production)			0.792***(0.299)
Ln (US per capita Renewable Electricity Production)			1.04 (0.765)
R^2	0.58	0.59	0.58
Number of Observations	491	491	491
Number of Bootstrap Replications	2305(2353)	2280(2311)	2162(2199)

Note: Bootstrap standard errors are in parenthesis. The required number of bootstrap replications are in parenthesis where completed replications in STATA 15 are given *** Significant at 1%, ** at 5%, and * at 10%.
Required number of bootstrap replication is determined by Poi (2004) method with STATA command.

Table 2. 6: OLS Estimation of Gravity model with Bootstrap Standard Error with importer fixed effect and time fixed effect [Dependent Variable Ln (wood pellets quantity of imports)]

Variable	Scenario 1	Scenario 2	Scenario 3
Intercept	-214.16* (126.50)	-168.294 (130.96)	-193.78 (127.27)
Ln (Importer's Renewable Electricity Production)	0.807*** (0.295)		
Ln (US Renewable Electricity Production	1.16 (0.827)		
Ln (US GDP Per Capita)	19.85* (11.79)	20.98*(11.69)	20.43*(11.67)
Ln (exchange rate)	0.067 (0.212)	0.087(0.210)	0.0688 (0.199)
US Renewable Policy	1.39** (0.605)	1.42**(0.600)	1.40**(0.599)
Importer's Targeted Renewable Policy for biomass production	0.078 (0.710)	0.093(0.711)	0.068 (0.710)
Importer's General Policy RES production (obligations, quota RPS and others)	0.343 (0.866)	0.295(0.871)	0.344 (0.848)
Importer's Research and Development Policy for Biomass Production	-1.01*(0.575)	-1.00*(0.569)	-1.01* (0.075)
Barrier Policy	-2.84***(0 .711)	-2.84***(0.698)	-2.83***(0.719)
Ln (Importer Share of Renewable Electricity Production in GDP)		0.839***(0.286)	
Ln (US Share of Renewable Electricity) Production in GDP		1.19 (0.837)	
Ln (Importer's Per capita Renewable Electricity Production)			0.796*** (0.306)
Ln (US per capita Renewable Electricity Production)			1.16 (0.788)
R^2	0.60	0.60	0.60
Number of Observations	491	491	491
Number of Bootstrap Replications	1851(1878)	2317(2349)	2221(2250)

Note: Bootstrap standard errors are in parenthesis. The required number of bootstrap replications are in parenthesis where completed replications in STATA 15 are given *** Significant at 1%, ** at 5%, and * at 10%.
Required number of bootstrap replications is determined by Poi (2004) method with STATA command.

Chapter 3: Examining the Potential of Camelina as Feedstock for Renewable Jet Fuel

Abstract

The US Federal Aviation Administration (FAA) targets of using 1 billion renewable jet fuel each year have been increasing the interest in renewable aviation fuel. Camelina is an oilseed crop that has high oil content and has the potential to supply the renewable aviation fuel to the industry. Camelina can be produced as a rotation crop or a winter cover crop that can provide soil and environmental benefits. This study considers camelina production as winter cover crop. Cover crop production may avoid food versus fuel debate as well as provide higher net return to farmers. This study provides an economic analysis that includes the cost of producing camelina through a crop enterprise budget, yield variability of camelina across the US through Environmental Policy Integrated Model (EPIC) and stimulates a national supply curve of camelina under different price scenarios. The supply of renewable aviation fuel from camelina is also generated at the national level.

3.1 Introduction:

In the next two decades, commercial aviation will grow as the number of passengers increase. This commercial aviation growth rate will lead to an increase in carbon emissions and create a barrier to attain the reduced carbon emission target of International Civil Aviation Organization (UTIA Proposal). The Global Aviation Industry wants to achieve carbon-neutral growth by 2020 and reduce carbon emissions 50 percent by 2050 from its 2005 level (IATA 2009). There are four primary ways to achieve lower carbon footprints from Jet fuel emissions -- technology, operations, infrastructure, and economic measures. Technology has the most promising option to reduce carbon aviation emissions (Winchester et al., 2013). An essential part of this technological improvement is the role of renewable jet fuel. Use of renewable jet fuel produced from renewable biomass sources could reduce the carbon emissions by 80% on a full carbon life cycle basis (IATA 2009).

According to the International Air Transport Association IATA (2015) currently, total 22 airlines are using alternative fuel over 2000 commercial flights. The US Federal Aviation Administration (FAA) has established a target for the US aviation industry to consume one billion gallons of renewable jet fuel each year beginning in 2018 (Winchester et al. 2013). FAA is playing a significant role in the development of new renewable jet fuel and through April 2016, five new renewable jet fuel pathways had been approved (FAA 2017).

The objective of this study was to evaluate the potential of camelina (Camelina Sativa L.) as a renewable jet fuel. camelina is an oilseed crop from the mustard family that has a potential for biofuel production. Camelina seed contains 35-48% of oil, which is more than twice that of soybean’s oil content a shelf life of more than a year, and contains 35–40% alpha-linolenic acid, compared to 50–60% of flaxseed oil (Grady & Nleya 2010, Mupondwa et al.2016, FDA 2016).

This study used crop enterprise budgeting, crop simulation models such as the Environmental Policy Integrated Climate (EPIC) Model, and a national/regional partial equilibrium analysis model Policy Analysis System (POLYSYS) to determine the potential of camelina as a renewable jet fuel. This study evaluates the potential of camelina as biofuel feedstock by examining the cost of producing camelina, its yield variability for different locations, and its resulting potential supply curve. Economic impact estimates are provided using information on changes that might occur to the economy if a mature camelina-aviation fuel industry occurs.

POLYSYS is partial equilibrium model known as Policy Analysis System (POLYSYS) (Markel 2017). University of Tennessee's Agricultural Policy Analysis Center, US Department of Agriculture's Economic Research Service and Oklahoma State University's Great Plains Agricultural Policy Analysis Center jointly developed POLYSYS model (Walsh et al. 2003). POLYSYS is a model for the US agricultural sector that simulates agricultural policy. This model includes four modules; that is national demand (simultaneous block), regional supply (linear programming), livestock, and aggregate income modules. (De La Torre Ugarte et al. 2000).

3.2 Why Camelina?

Camelina can be produced both as a winter cover crop or a spring crop. Winter camelina would be planted in early October following soybeans and harvested in late June where wheat would follow it. Gesch & Archer (2013), found, that as a cover crop, camelina is profitable as it increases the yield of soybean at a reduced cost.

Camelina has several benefits as a biofuel feedstock. It has low input requirements with low herbicide and fertilizer cost (Robinson 1987). Camelina also has natural competitiveness with weeds (Grady & Nleya 2010). Camelina can be produced in dryland, non-irrigated and no-till production processes. Furthermore, camelina seed can be used as a high protein animal meal after oil extraction (Brandess 2012). Since camelina can be produced as a rotation crop, it avoids food versus fuel debate. Reimer & Zheng (2017), stated that camelina's current production acres could be expanded in the US without affecting food price.

In recent year's interest on the potential of camelina as a biofuel feedstock or biofuel has risen. Food vs. fuel debate is a significant issue while producing biofuel feedstock. Hence some studies are conducted on double cropping of camelina to avoid this food security issues. Chen et al. (2015), evaluates the camelina's agro-economic and economic potential with winter wheat rotation in the Northern Great Plains (NGP) from 2008-2011 in a replicative study. Their results suggested wheat yield is higher with the wheat rotation when compared to the wheat yield in a camelina wheat rotation. Thus, in the existing market price –the continuous wheat rotation was more profitable to the farmer than camelina-wheat rotation. However, scenario analysis of the study concludes that more optimizing lower production cost of camelina may increase the profitability of camelina-wheat rotation and make it more competitive with a wheat rotation for the farmers. Furthermore, the total biomass production and crop residue return to the soil are much higher in camelina–wheat than a continuous wheat rotation, suggesting that overall there will be improved in soil quality and productivity.

Sindelar et al. (2017), conduct a research review on camelina and pennycress double cropping method in US corn belt region with the rotation of corn and soybean. This review suggested that double cropping of energy crop will not deliver a feedstock for renewable aviation fuel production, integrating these crop systems could also potentially provide a range of ecosystem services. These services include soil protection from wind and water erosion, carbon sequestration, water quality improvement through nitrate reduction, and a food source for pollinators. However, the downside of double cropping also includes the yield reduction of the subsequent crop, for example, a yield reduction for soybeans in this crop rotation.

Gesch & Archer (2013), evaluated the feasibility of winter camelina as a double crop. This study conducted a 2-year field study in west central Minnesota from 2007-2009 in tilled and no-tilled soil with camelina planted before three different crops -- soybeans, oilseed sunflower, and forage millet. Results suggested that camelina and soybean net return is higher than the net return of the only soybean. Thus, the study concludes that in upper Midwest USA a winter camelina-food or -forage double-cropping system may be feasible.

Brandess (2012) used a crop rotation budget to estimate the economic feasibility of producing camelina as a biofuel feedstock for firms in northeastern Colorado. The crop rotation in this study was corn, camelina, and wheat. The results suggested that camelina has a 50% probability of profitable returns when the price of diesel fuel is greater than $4.30/gallon. This study concludes that revenue generated from the sale of camelina meal is the most influential factor.

Natelson et al. (2015), evaluates the commercial production of jet fuel from camelina oil through hydrolysis, decarboxylation. According to this study, the jet fuel break-even selling price was $0.80/kg, and refinery has a nameplate capacity of 76000 cubic meter hydrocarbons.

Stain (2012) used a partial equilibrium model with a break-even price to determine the supply curve of camelina in the Northwest region including the states of Idaho, Montana, Oregon, and Washington. Results suggested that at a price of $0.15/lbs. of camelina, farmers would produce an estimated 1.76 billion lbs. from 1,493,684 acres. The author assumed that all the acres will be transformed to a wheat-camelina rotation when this rotation is more profitable than current crop rotation. Land use for camelina production reduced to 72,213 acres when a 5% adoption rate is applied to the low and intermediate rainfall zone.

Mupondwa et al. (2016), denotes a techno-economic analysis for camelina as a renewable jet fuel in Canadian prairies land. This study used an engineering economic model to evaluates the capital investment, scale, production cost, and profitability for an extraction plant with a capacity of 120,000–1,500,000 tons per annum. Furthermore, the study considers farm production cost for a different range of camelina yield, the supply of camelina, the location of the plant, transportation to the plant, processing technology and plant cost to determine the profitability and break-even price of camelina as a renewable jet fuel. The results suggest that the estimated capital investment was $24.7 - $155 million for a crushing plant with capacity mentioned above, where feedstock cost $0.29–0.40 per kg, seed yield is 1400–2100 kg per hector, the range of oil content is 38%–47%. The camelina meal revenue is the crucial factor of the break-even selling price and determine the competitiveness of camelina oil as a feedstock. The production cost of producing camelina feedstock determines 81%–90% of operating cost. Larger crushing plants have a lower break-even selling price compared to smaller plants. The breakeven price ranges from $0.43 -$1.22 $L^{-1.}$ Thus, the study concluded that the large plant enjoyed the better economies of scale in the production of renewable jet fuel from camelina.

Li, Mupondwa & Tabil (2018), further extend their previous techno-economic analysis and evaluates the commercial production of hydro-processed renewable jet (HRJ) fuel from camelina in Canadian Prairies. This study estimates a capital investment, scale, and profitability of producing HRJ and co-products (biodiesel, naphtha, LPG, and propane) based on biorefinery plant sizes of 112.5–675 million L per annum. The results suggested that the minimum selling price of HRJ was $1.06 per litter for a biorefinery plant with the size of 225 million L. Moreover, the range of minimum selling price may vary from $0.40-$1.71 per littler, and the variation of selling price depends on plant capacity, feedstock cost, and co-product of HRJ. The region can support an HRJ pant with a capital investment of $167 million with a capacity of 675 million L per annum based on analysis of marginal and average cost.

Reimer & Zheng (2017) develop a general equilibrium model and evaluate the sustainability of the supply chain of camelina as renewable jet fuel. This study examines different scenarios that include a change in consumer demand for renewable jet fuel, tax, and subsidies policies. Assuming canola prices and its supply chain, results suggest that camelina as a renewable jet fuel would be competitive with conventional fuel when there is a 17% subsidy on the alternative fuel, or a 20% tax on the conventional fuel, or a combination 9% subsidy on the alternative and 9% tax on the conventional fuel.

Markel (2017), assesses the potential of Pennycress as a feedstock to produce renewable jet fuels. This study used a similar methodology as this study is going to use to evaluate the potential of camelina as renewable jet fuel. According to POLYSYS stimulation pennycress will be planted on 6.65 million acres when the price level is $0.05 per pound. By 2020 with the assumed market price of 0.15, 20.17 million acres will be planted, and that will produce 24,245 million pounds of pennycress seed and once the seed is crushed, 8,486 million pounds of pennycress oil. Finally, this study concluded that Pennycress has a potential to supply 600-800 million gallons of renewable jet fuel.

3.3 Conceptual Framework:

The optimal decision thus becomes that of evaluating tradeoffs in profit generated by the current land use practice (defender) and that generated with a different crop such as camelina (challenger). The expectation is that the producer wishes to maximize his/her expected net return

(NR). Pairwise comparisons are made between current land use, the defender (D), and the potential new land use, the challenger (C), by comparing the profit generated by each. According to the concept of profit maximization, a farmer will produce a crop if the net return will be,

$$\mathrm{NR} = \mathrm{P} * \mathrm{Y} - \mathrm{OC} \quad (3.1)$$

where NR is net return and farmers want to maximize its net return subject to price (P), yield (Y) and operational cost of production (OC)

Hence if assumes there is two crop practice defenders (traditional crop practice corn-soybean) and challenger new crop practice that includes camelina rotation (corn-camelina-soybean). Now if defender crop practice has net return NRd and challenger has net return NRc. Thus, the farmer is to select between the two crop practices; they will choose that crop which gives a higher net return. (Mooney, Larson, English, & Tyler, 2012). If modify the equation 3.1, for crop challenger and crop defender respectively we have the following two equations,

$$NR_C = \mathrm{Pcorn} * \mathrm{Ycorn} + \mathrm{Pcam} * \mathrm{Ycam} + \mathrm{Psoy} * \mathrm{Ysoy} - \mathrm{OCcorn} - \mathrm{OCcam} - \mathrm{OCsoy} \quad (3.2)$$

and $NR_d = \mathrm{Pcorn} * \mathrm{Ycorn} + \mathrm{Psoy} * \mathrm{Ysoy} - \mathrm{OCcorn} - \mathrm{OCsoy}$ (3.3)

Pcorn, Ycorn is price and yield, of corn, respectively; and OCcorn, is the operational cost of corn production, Pcam, Ycam is the price and yield of camelina, respectively; and OCcam is the operational cost of producing camelina and Psoy, Ysoy is price and yield of soybean and OCsoy is the operational cost of producing soybean. Thus, the farmer will maximize NR depends on price, yield and operational cost of crops. Therefore, the farmer will choose challenger over a defender when NRc>NRd based on all price, yield, and operational cost of each crop (Mooney et al., 2012).

This study assumes camelina will be produced as a winter cover crop between corn and soybeans, so it is competing with rotational practices as well as other crops. Hence farmers will choose to plant the cover crop camelina when the net return for producing this corn/camelina/soybean rotation exceeds other alternatives like above the net return of corn-soybean practices.

Furthermore, production of a cover crop may reduce the yield of the subsequent crop. soybean yield may be reduced because of camelina harvest might delay soybean planting. This reduced yield will reduce the profitability of the soybean crop, so if the camelina profitability can cover up the reduced profitability of soybean and altogether corn-camelina-soybean rotation profitability is higher than corn-soybean rotation profitability, in other words, NRc>NRd only then farmers will choose challenger (alternative crop practice) over defender (traditional crop practice).

3.4 Method:

This study develops the crop enterprise budget and estimates the break-even yield for a given price level. Then using the Epic model, a growth simulator, determines regional yields of the cover crop camelina. Finally, these yields are placed into POLYSYS to determine potential supply of camelina, price impacts on current crop production, and land use change. Finally, based on camelina oil content, the potential supply of renewable jet fuel is determined.

Camelina yields range from 500-1500 lbs./acre in peer-reviewed studies and its range in non-peer reviewed studies is 1500- 3000 lbs./acre (Brandess, 2012). These yields vary depending on location, management practice, and weather among other variables. For the partial budgeting portion of this study, a yield of 1050 lbs./acre was determined from a double cropping of winter camelina with soybean field trial in Minnesota (Gesch & Archer, 2013a). Camelina seed price is

$2.00 per pound is taken from Brandess (2012), and Hancock Seeding (2018). Furthermore, the crop enterprise budget sets the price of camelina at $0.28 in 2015 dollars and inflated to 2016 dollars (Chen et al. 2015).

Finally, since camelina is grown as a cover crop following corn and preceding soybeans the crop enterprise budget assumes the level of Nitrogen, Phosphorous, Sulfur and pre-plant herbicide application rates as suggested by Robinson (1987) and Gesch & Archer (2013a). Variable expenses, therefore, include costs for seed, fertilizer and chemical cost, repair and maintenance, fuel oil and filter, operator labor, machinery required for broadcast planting, and operating interest. Fixed costs incorporated in the budget include the costs consists of machinery, capital recovery, and taxes, housing, and insurance. Some of the cost may vary from region to region, thus this budget assumes except fertilizer cost machinery and other fixed and variable cost are same for all over US.

However, this study uses fertilizer index in crop enterprise budget for nine farm regions and calculates different fertilizer cost for every nine regions. Hence, this budget has nine summary budget that gives a clear direction for how the input cost may vary from one region to another. Fertilizer and herbicide cost are taken from UT Extension Canola Crop Budget 2017 and 2018 and then fertilizer index for each POLYSYS region is used to calculate fertilizer cost by different farm regions. The machinery and other operating cost are calculated in accordance with the American Agricultural Economics Association Cost and Return Handbook (AAEA 2000) and American Society of Agricultural Engineers (ASAE) Standards (ASABE 2006).

In a second step, EPIC is used to examine how different exogenous variables will impact yield. The EPIC model was developed in 1980 in the US Initially this model was constructed to examine the impacts of soil erosion for a multitude of land management practices on productivity.

Since then, the model has been modified to become a complete tool to study the agro-ecosystem process. (Rinaldi & de Luca 2012). “It is a process-based computer model that simulates the physicochemical processes that occur in soil and water under agricultural management” (EPIC, 2014).

The EPIC model version 0810 is used to develop yield estimates for 305 POLYSYS region. Using a PHU of 1050, no water stress for crops, dryland production of camelina, and fertilizer application rates consistent with the crop enterprise budget of Nitrogen at 70 lbs./acre and Phosphorous at 30 lbs./acre. Using the management practice represented in the enterprise budget and the spatial costs in EPIC, results for each POLYSYS region was obtained. EPIC simulated 100 years of a corn, camelina, and soybean rotation and provided regional yields. This model provided 50 yield estimates for each crop in per POLYSYS region. These yields were then averaged for camelina to determine a yield for each POLYSYS region.

This study has used the POLYSYS model to generate a regional and national level of the supply curve for camelina. The average regional camelina yield generated from the EPIC model is used in the POLYSYS Model along with different fertilizer costs reflecting regional fertilizer prices. In crop enterprise budget this study has changed fertilizer cost for nine regions, and then this budget is used in POLYSYS by using spatial interpolation method. There are nine farm region budget points and using these points interpolate the cost for 305 POLYSYS regions. POLYSYS provide estimates of crop production and supply of camelina, at the county level for the 48 contiguous states of United States. These data will be aggregated to the national level to determine the supply potential of camelina and its impacts on commodity prices, land use change, and agricultural net returns, for all major crops – barley, corn, cotton, hay, oats, rice, sorghum, soybeans, and wheat. Profit-maximizing land allocation decisions will make based on annual net returns. Ex post analysis will be conducted to determine the cost of renewable jet fuel. This cost will include the cost of crushing camelina seed into camelina oil and the cost of converting the oil into green jet fuel.

3.5 Results:

3.5.1 Farm-Gate Cost:

The budget provided an estimated total variable cost of $123.31 per acre and the total fixed cost of $33.04. The return above variable expenses is estimated at $169.84 and a return above variable and fixed expenses are $136.80.

These values are based on 1050lbs/yield per acre and a seeding rate of 5lbs per acre. The break-even yield is estimated at 560 lbs./acre when the market price is $0.28 per pound (see table 3.10). The breakeven price for a yield of 1050 pounds per acre is calculated to be $0.12 per pound to cover variable expenses and $0.15/lbs. to cover total expense (see table 3.11). These results will differ depending on location since productivity and variable input prices will vary.

The tornado diagram of Figure 3.1 based on the crop enterprise budget demonstrates how a +20% or -20% change in different variables, i.e., camelina price, camelina yield, nitrogen quantity, camelina seed price, camelina seed quantity, nominal interest, and fuel cause fluctuations in net return. As expected, the variables having the largest impact on camelina's net return are camelina price and camelina yield. An increase in price causes a rise in the net return where a decrease in price reduces net return. Furthermore, in the case of camelina yield; a 20% higher yield increase the net return significantly, but 20% lower yield has a small effect compared to the higher yield change. In contrast, changes in nominal interest induce a very small change in net return or almost remain constant. Finally, change in nitrogen quantity, fuel price, camelina seed quantity, and camelina seed price have an inverse relationship with the net return. A 20% increase in these variables reduce the net return where a 20% decrease in these variables increases the net return.

As the fertilizer cost is changing in the nine-farm region variable cost is also changing at the country level, and the range of variable cost is varying from $123-$132 approximately.

3.5.2 EPIC Results:

The range in camelina yield goes from 1.62 lbs./acre to 5631 lbs./acre. With the average over the United States being 1040 lbs./acre and a standard deviation of 769 lbs./acre. The highest regional average yield is 2632 lbs./acre with the lowest regional average yield is 292 lbs. /acre. The lowest average yield occurs in North Dakota because of the extreme weather conditions in winter where the three highest yields are located in Louisiana, and Mississippi with mild winters.

Based on yields alone, it appears that the most suitable regions for camelina production according to EPIC in the southern part the US; Texas Florida, Louisiana, Mississippi to sections of the Midwest including portions of Kansas to Illinois, along with part of Indiana and Oklahoma. Furthermore, a tiny part of California and Orgon has a good average yield according to EPIC results (Figure 3.2).

The upper Northern part of US, Northwest Part has a very low average yield which is range from 290 lbs./acre to 500 lbs./acre. This result is caused by both elevation and rainfall. The extreme winter condition in North Dakota, Minnesota, South Dakota, makes it challenging to grow camelina as a cover crop. Furthermore, the mountainous areas of Colorado, Wyoming, Washington, Idaho, and their weather is not suitable for winter cover crop camelina production. Moreover, all other region has a moderate yield of 501 lbs./acre to 1000 lbs./acre.

The standard deviation of camelina yield ranges from249 lbs./acre to 1351 lbs./acre. A visual analysis of the yield standard deviation demonstrates that a pattern exists. Those regions that have higher standard yield deviations typically have has a lower estimated average camelina yield (see Figure 3.3).

3.5.3 POLYSYS Result:

Analyzing POLYSYS results, there is no production of camelina in the baseline scenario when camelina price equals $0.0. As the price increases from $0.05 to $0.50 per pound, production of camelina seed increases (Table 3.1). The acreage planted, seeds harvested, and estimated camelina jet fuel production over each camelina seed price is calculated as average and presented in table 3.1. Camelina seed total supply estimates range from 5380.78 million pounds to 22776.06 million pounds at the price range of $0.05-$0.50. At a price $0.05, the total supply of camelina seed is 5380.78 million pounds, acreage planted is 8.84 million acres, and renewable jet fuel is produced is 155.44 million gallons[3]. Furthermore, at price level $0.30 (as the crop enterprise budget is based on the price level of $0.28, so $0.30 is the closes price scenario) 18903.17 million pounds of camelina seed is produced where 34.47 million acres are planted for camelina and that produced 546.09 million gallons of renewable jet fuel. Finally, at the highest price level of $0.50, 44.66 million acres of camelina is planted, and 22776.05 million pounds of camelina seed is produced that can produce 657.97 million gallons of renewable jet fuel.

[3] Camelina oil content is 40% so with a 40%of oil content 2085 million pounds of Camelina produce 5380.78*0.40=2152.31 million pounds of vegetable oil and according to Markel (2017) the 100 pounds of vegetable oil contain 49.4 pounds of Jet fuel, hence 2152.31*0.494=1053.24 million pounds of Jet fuel is produced. 1 gallon of jet fuel contains 6.84 pounds of jet fuel thus 1063.24/6.84=155.44 million gallon of jet fuel produced for this given price.

Furthermore, Figure 3.4 shows Camelina feed renewable jet fuel supply for the given price range of $0.05-$0.50. The curve is upward slopping that means as the price of camelina increases it increases the camelina seed production thus Jet fuel production of camelina.

Table 3.2, Table 3.3, Table 3.4 and Table 3.5 present the change in acres planted, total supply, yield, price, and net returns for all primary crop production in two price scenarios. Table 3.2, and Table 3.3 compare the baseline variables with $0.25 scenario variable where Table 3.4 and Table 3.5 compare baseline with $0.50 scenarios. In Table 3.2 the acres planted decline from baseline to scenarios alternate scenario for all major crops except corn and soybean where yield increases for all crops from baseline to alternative scenario except for Hay. Table 3.2 showed that Camelina is planted in a corn-soybean rotation. However, the corn acres include both single-crop and double-cropping methods of summer corn and winter camelina production, thus corn production acres increase by 1.88% from baseline scenario in this alternate scenario.

According to the Table 3.3 the total supply of corn and soybean increase from the baseline to the scenario one where all other crops total supply declines or remain constant. Corn supply increases 3.29% where soybean total supply increases by 3.42%. On the other hand, grain sorghum, oats barley, wheat, cotton, and total rice supply declines from baseline to scenarios one where the total supply of hay remain constant with baseline.

Furthermore, in Table 3.4, the net returns increase for all crops from baseline to alternate scenarios except grain sorghum, cotton, and rice. Finally, corn, oats, and soybean price decline from baseline to an alternate scenario where grain sorghum, barley, wheat, cotton, and rice price increases from baseline to alternate scenario and hey price remain constant.

In addition to that Table 3.4 at $0.50 price scenarios shows that the acres planted increased only for corn and soybean from baseline scenarios because of the reason discussed above. The increase in production acres for corn and soybean are increased 5.37% and 5.26% respectively from the baseline. Furthermore, all other crops production acres decline from baseline expect hay production acres remain constant. Moreover, the yield for all crops increases expects hay yield remains constant. This table also shows that the total supply of corn increases 8.59%% from baseline to the alternate scenario of $0.50 price of camelina and for soybean, this increase is 0.13%. The total supply of oats increases by 1.84% where all other crops supply declines. In Table 3.5, the net return rises for all crops except grain sorghum and cotton net return declines. The price of corn reduces by 18.06%% where the price of soybean declines by 0.25%.

Finally, in all the above tables in the baseline, there is no camelina production and in Table 3.2 alternate scenario camelina is harvested in 30.31 million acres with an average yield of 596 pounds per acre and the total supply of 17145 million of pounds of camelina that induces the net return of $549.01 million. In contrast, with a price level of 0.50 in table 3.3 camelina is harvested in 44.66 million of acres with an average yield of 537 pounds per acre approximately that supply 22776 million pounds of camelina with a high net return of $5881.19 million. The net return for camelina increases significantly from $549.01 million to $5881.19 million from table 3.2 to table 3.3 with $0.20 increases in price.

3.5.4 Plant Gate Cost:

The plant gate cost is divided into two parts, one is the cost of crushing facility that will convert camelina seed to vegetable oil and the second one is the cost of green jet fuel production from camelina oil. All the parameters for two cost calculation are based on the secondary source of literature. Both vegetable oil conversion and jet fuel conversion are based on two basic cost parameters; capital cost and operating cost of the conversion facility.

Table 3.6 represents the vegetable oil crushing plant cost. A vegetable oil plant with a nameplate capacity of 30,588,235 gallons with a $0.28 market price of camelina and 1050/lbs. Yield total capital cost is $2.77 per gallon, the total operating cost is $1.41 per gallon and the total cost is per gallon is $4.18. This calculation assumed the oil content of camelina is 40% which is taken as the midpoint of various literature. The all cost parameters for this crushing facility is taken from Shumaker et al. (2014) where the total capital cost is the sum of capital feedstock cost, capital transportation cost, and capital conversion cost. Furthermore, total operating cost includes operating cost of conversion, transportation, operating cost of feedstock and operating credit.

Table 3.7 is representing the summery of green jet fuel conversion of camelina. According to this table, the total cost of camelina jet fuel per gallon is $4.55 where operating cost is $3.60 per gallon, and capital cost is $0.95 per gallon. In this table the operating cost is the sum of the operating cost of hydro-processing, operating cost of conversion, transportation, operating cost of feedstock and operating credit.

Furthermore, Table 3.8 represents the cost of camelina jet fuel per gallon when the crushing facility buys camelina oilseed rather than camelina oil. In that case, the total cost of camelina-based green jet fuel become $6.67/per gallon where operating cost $5.72 per gallon and capital cost is $0.95 per gallon. Hence, these results suggest that when crushing facility buy camelina seed, it increases it operating cost of producing camelina-based green jet fuel. The cost parameters for Table 3.7 and Table 3.8 is based on Markel (2017), (English et al., 2016) and Shumaker et al. (2014).

3.6 Conclusion:

This study has used a crop enterprise budget, EPIC model, and partial equilibrium analysis POLYSYS model to evaluate the potential of winter cover crop Camelina as a renewable jet fuel. The crop enterprise budget is based on a fixed yield of 1050 lbs./acre Where the price of camelina is $0.28, and a seeding rate of 5 lbs./acre and camelina seed oil content is 40%. All the assumption is based on various literature, and the results of the budget suggest that the range of net return is $128- $139 per acre approximately based on different farm region cost. Each region cost has a breakeven yield for a given price of $0.28, and for a given yield there is the breakeven price.

The sensitivity analysis and Tornado diagram represent that how the net return can fluctuate by changing specific variables. i.e., camelina price, nitrogen quantity, nominal interest, fuel cost, camelina yield, camelina seed quantity and camelina seed price. The diagram showed that camelina yield and camelina price caused the highest variability in net return.

Furthermore, the EPIC model suggests the suitable region for Camelina production based on average yield for each 305 POLYSYS regions. The yield of Camelina varies from each region based on temperature, water stress, and type of soil. However, depending on the variable cost of producing camelina on that region and price of Camelina will play a significant role in the production of camelina.

The average yield for 305 POLYSYS region and the crop enterprise budget is used as input in a partial equilibrium model POLYSYS and stimulate different price scenarios of Camelina production. The price scenarios are ranges from $0.05 -$0.50 with a break of $0.05 between each price level. The stimulation period ranges from the year 2018-2036 and the study calculated the average for the year 2019-2036 for each price level. The results suggest that with an increasing price the acreage of camelina production, total camelina production of a million pounds and camelina oil production increases. The results also show that the acres planted, the total supply and the return of corn, and soybean increases from baseline when compared to alternate scenarios. At the price level $0.30, 18903.17 million pounds of camelina seed is produced where 34.47 acres are planted for camelina and that produced 546.09 million gallons of renewable jet fuel. Finally, the camelina has potential to supply 155.44 million gallons to 669.67 million gallons of renewable jet fuel based on different price level on an average.

The study assumes an average price of camelina over the period of 2018-2036, so the change in price will also alter the situation for camelina production. Furthermore, for all other crops, the current forecasted commodity price was used, and change in price will also alter the situation for all crops. This study does not include any of the policy stimulation situations in camelina production. The different incentive for camelina production or in renewable jet fuel production may also change the market demand for camelina production and farmers decision to produce the crops.

Finally, the crop enterprise budget results are a little bit conservative as they are based on a price of camelina as $0.28 in the crop enterprise budget with a fixed yield of 1050 lbs./acre. Depending on the region yield may go to 2500 lbs./acre and that may affect the net return significantly. On the other hand, a higher camelina price may make camelina as a more viable option. Furthermore, if the renewable jet fuel conversion facility can cover a portion of their cost through government subsidies, it will also increase the demand for camelina production in future.

The policy stimulation or different government support program effect is acknowledged and left for future research. In addition to that, this study only examines the corn-camelina-soybean rotation, in some region wheat-camelina rotation or any other rotation will be more profit maximizing thus more feasible option for farmers. This limitation is also left for future research.

Another additional limitation is this study does not include the opportunity cost of forgone soybean yield to its cost calculation which may also include in future research.

References:

(ITA). (2016). *2016 Top Markets Report Renewable Fuels Country Case Study: South Korea*. https://doi.org/10.5817/CP2013

AAEA. (2000). *Commodity Costs and Returns Estimation Handbook*.

ASABE. (2006). *Tractors and self-propelled machines for agriculture and forestry--Operator enclosure environment-Part 2: Heating, ventilation and air-conditioning test method and performance*. St. Joseph, MI: ASABE. https://doi.org/https://doi.org/10.13031/2013.23566

Brandess, A. (2012). *Modeling the Profitability of Camelina Sativa As a Biofuel Feedstock in Eastern Colorado*.

Chen, C., Bekkerman, A., Afshar, R. K., & Neill, K. (2015). Intensification of dryland cropping systems for bio-feedstock production: Evaluation of agronomic and economic benefits of Camelina sativa. *Industrial Crops and Products*, *71*, 114–121. https://doi.org/10.1016/j.indcrop.2015.02.065

EPIC. (2014). *Environmental Policy Integrated Climate Model*.

FAA (2017) Retrived from: https://www.faa.gov/news/updates/?newsId=85425 Last Visited: July, 25th, 2018

FDA. (2016). *Original submission*. Retrieved from http://www.fda.gov/Food/IngredientsPackagingLabeling/GRAS/NoticeInventory/default.htm

Gesch, R. W., & Archer, D. W. (2013a). Double-cropping with winter camelina in the northern Corn Belt to produce fuel and food. *Industrial Crops and Products*, *44*, 718–725.

https://doi.org/10.1016/j.indcrop.2012.05.023

Gesch, R. W., & Archer, D. W. (2013b). Double-cropping with winter camelina in the northern Corn Belt to produce fuel and food. *Industrial Crops and Products*, *44*, 718–725. https://doi.org/10.1016/j.indcrop.2012.05.023

Grady, K., & Nleya, T. (2010). *Camelina Production*. *Agriculture*.

Li, X., Mupondwa, E., & Tabil, L. (2018). Technoeconomic analysis of biojet fuel production from camelina at commercial scale: Case of Canadian Prairies. *Bioresource Technology*, *249*(July 2017), 196–205. https://doi.org/10.1016/j.biortech.2017.09.183

Markel, E. L. (2017). *Analysis of a Market for Tradable Credits , Policy Uncertainty Effects on Investment Decisions , and the Potential to Supply a Renewable Aviation Fuel Industry with an Experimental Industrial Oilseed*.

Mooney, D. F., Larson, J. A., English, B. C., & Tyler, D. D. (2012). Effect of dry matter loss on profitability of outdoor storage of switchgrass. *Biomass and Bioenergy*, *44*, 33–41. https://doi.org/10.1016/j.biombioe.2012.04.008

Mupondwa, E., Li, X., Tabil, L., Falk, K., & Gugel, R. (2016). Technoeconomic analysis of camelina oil extraction as feedstock for biojet fuel in the Canadian Prairies. *Biomass and Bioenergy*, *95*, 221–234. https://doi.org/10.1016/j.biombioe.2016.10.014

Natelson, R. H., Wang, W. C., Roberts, W. L., & Zering, K. D. (2015). Technoeconomic analysis of jet fuel production from hydrolysis, decarboxylation, and reforming of camelina oil. *Biomass and Bioenergy*, *75*, 23–34. https://doi.org/10.1016/j.biombioe.2015.02.001

Reimer, J. J., & Zheng, X. (2017). Economic analysis of an aviation bioenergy supply chain. *Renewable and Sustainable Energy Reviews*, *77*(April 2016), 945–954. https://doi.org/10.1016/j.rser.2016.12.036

Rinaldi, M., & de Luca, D. (2012). Applications of EPIC model to assess climate impact on sorghum in southern Italy. *Italian Journal of Agronomy*, *7*(1), 74–85. https://doi.org/10.4081/ija.2012.e12

Robinson, R. G. (1987). Camelina: a useful research crop and a potential oilseed crop. *Minnesota Ag. Expt. Stn. Bull. 579,* 2–12.

Sindelar, A. J., Schmer, M. R., Gesch, R. W., Forcella, F., Eberle, C. A., Thom, M. D., & Archer, D. W. (2017). Winter oilseed production for biofuel in the US Corn Belt: opportunities and limitations. *GCB Bioenergy*, *9*(3), 508–524. https://doi.org/10.1111/gcbb.12297

Winchester, N., McConnachie, D., Wollersheim, C., & Waitz, I. A. (2013). Economic and emissions impacts of renewable fuel goals for aviation in the US. *Transportation Research Part A: Policy and Practice*, *58*(2013), 116–128. https://doi.org/10.1016/j.tra.2013.10.001

Appendix:

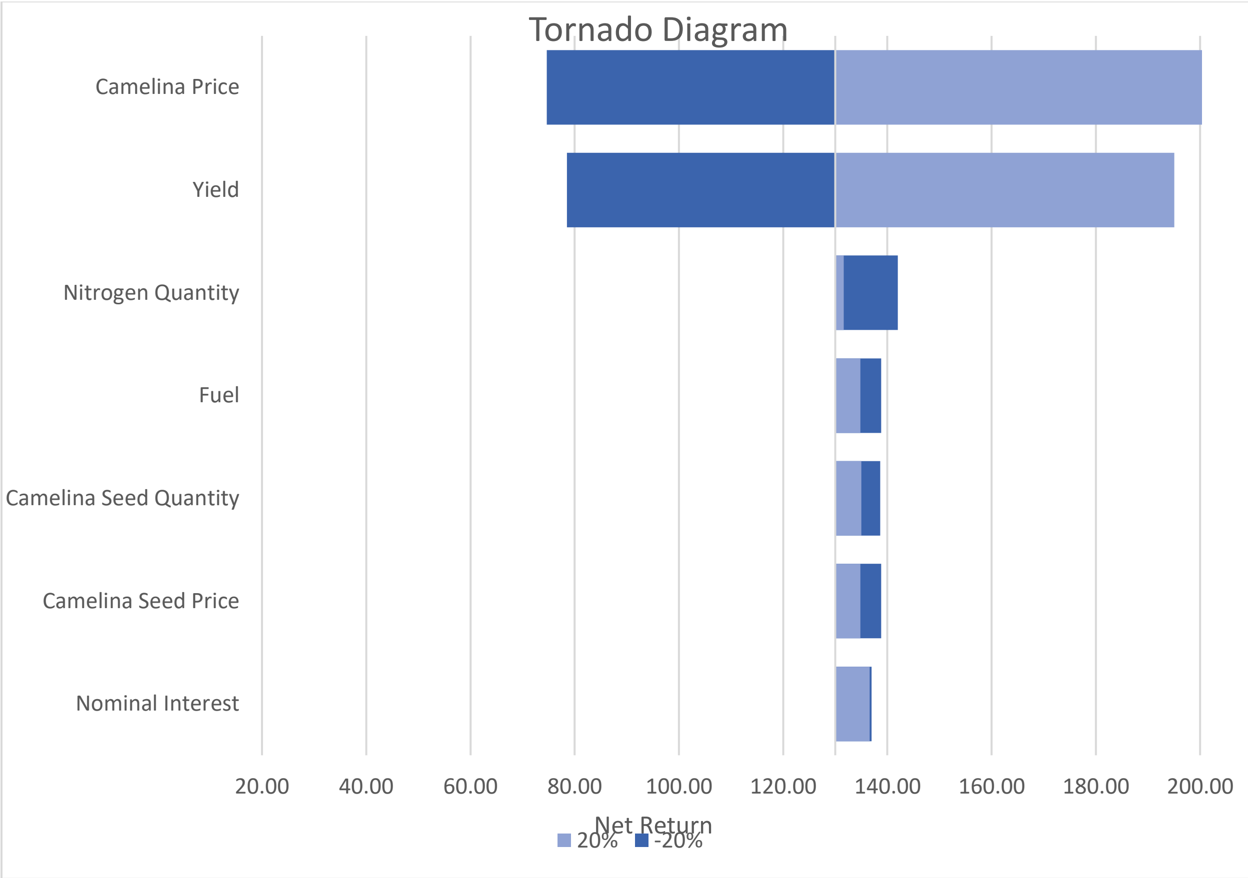

Figure 3. 1: Tornado Diagram for Net Return

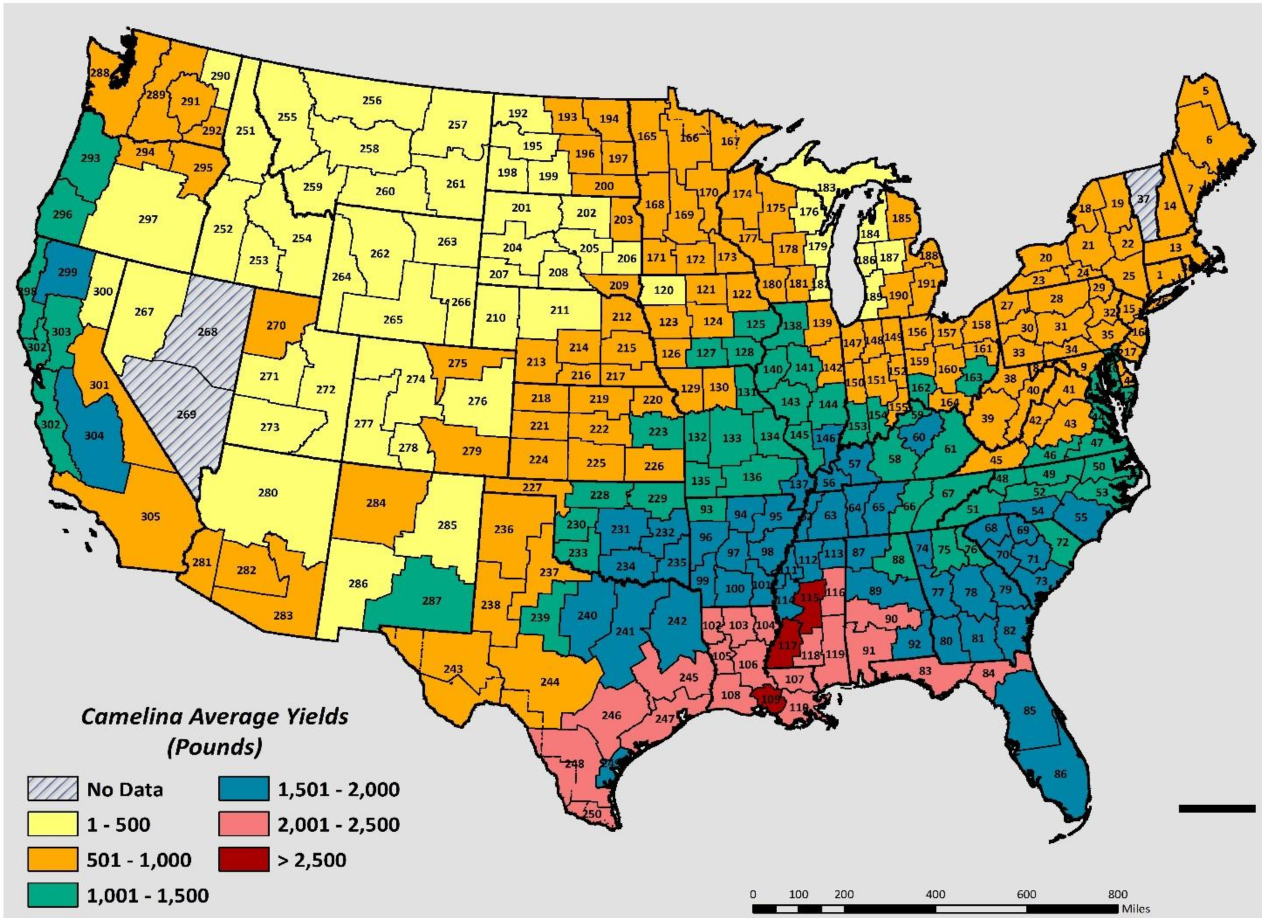

Figure 3. 2: Calculated Mean Camelina Yield as a Cover Crop for 305 POLYSYS Regions

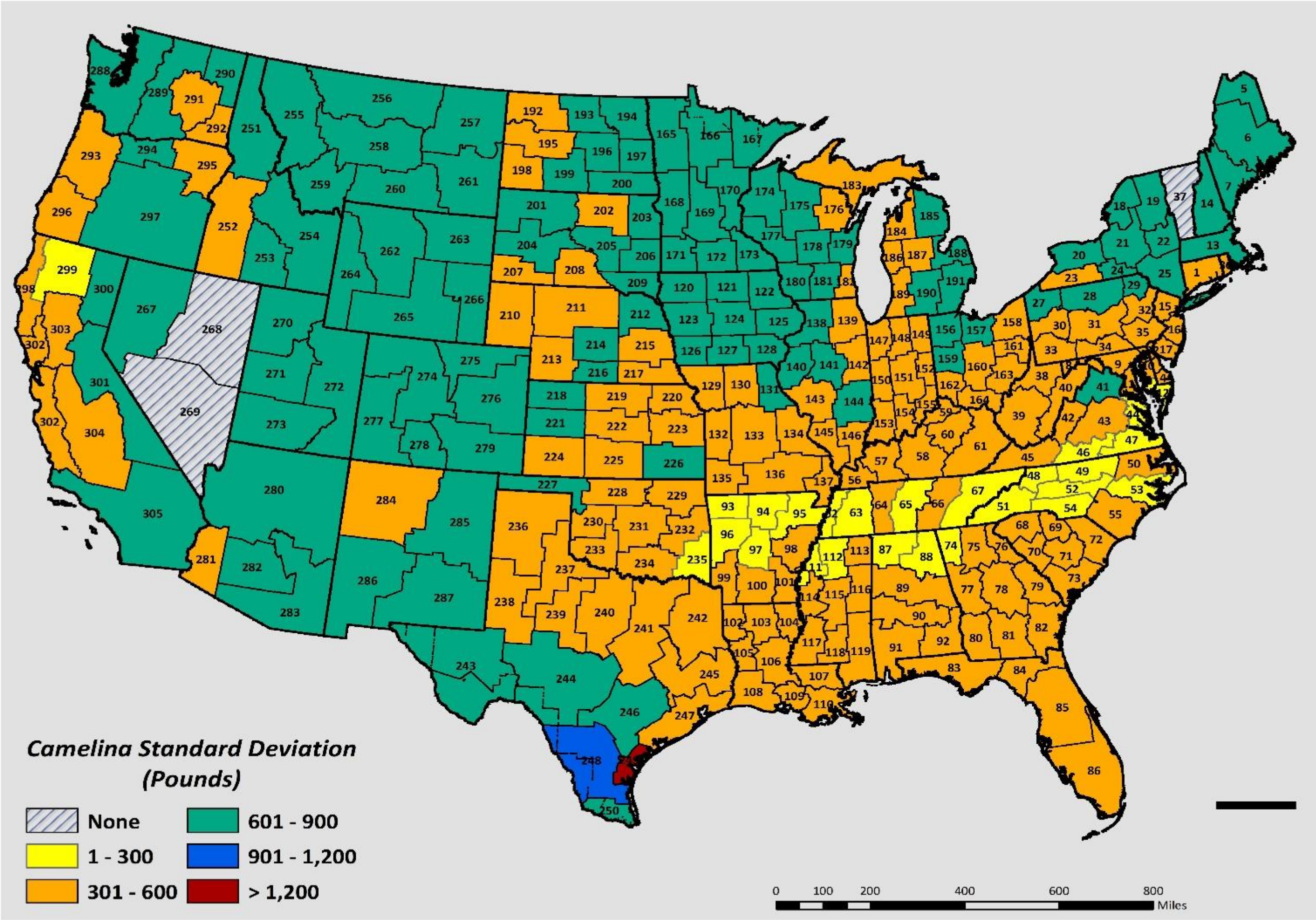

Figure 3. 3: Calculated Standard Deviations for Camelina Yield as a Cover Crop for the 305 POLYSYS Regions

Table 3. 1: Production of Camelina, Acreage Planted, and Renewable Jet Fuel Production (Figures in millions)

Production of Camelina, Acreage Planted, and Renewable Jet Fuel Production			
Price	Production (in Million lbs.)	Acreage (in million acres)	Renewable Jet Fuel (in million gallons)
$0.00	0	0	0
$0.05	5380.78	8.84	155.44
$0.10	8057.61	12.51	232.78
$0.15	10916.28	17.18	315.36
$0.20	14320.89	24.05	413.71
$0.25	17145.00	30.31	495.30
$0.30	18903.17	34.47	546.09
$0.35	20242.28	37.76	584.78
$0.40	21372.22	40.61	617.42
$0.45	22186.72	42.89	640.95
$0.50	22776.06	44.66	657.97

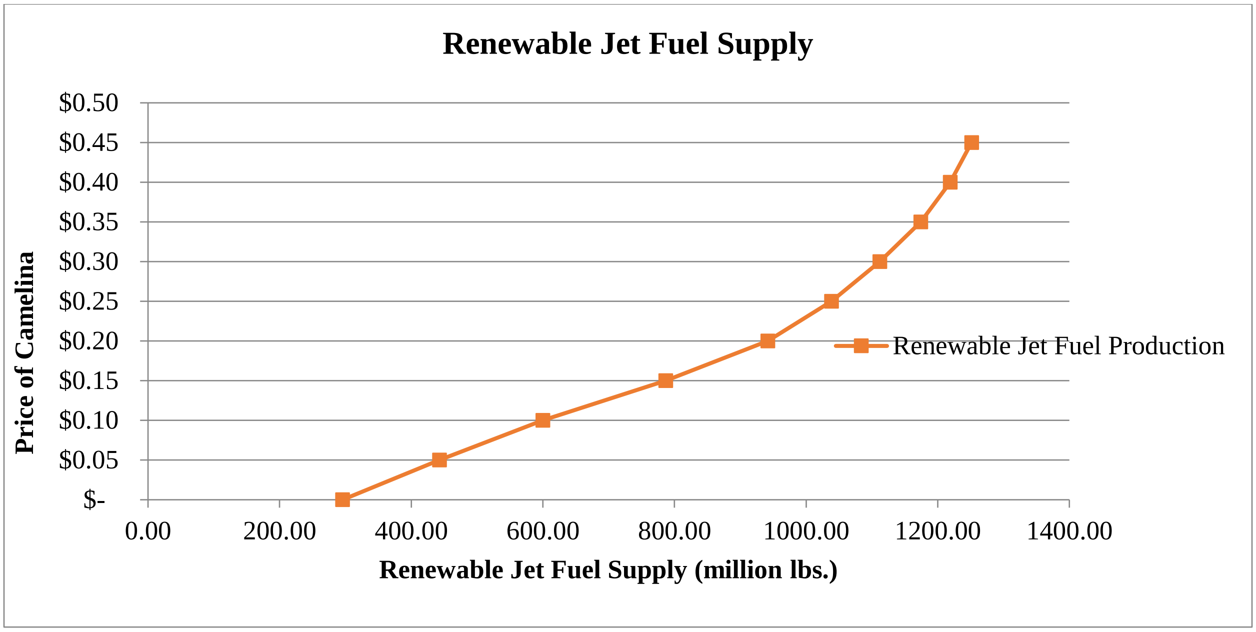

Figure 3. 4: Camelina Renewable Jet Fuel Supply Curve

Table 3. 2: Changes from Base Case to Alternate Scenario with Camelina Price of $0.25 per pound for Harvested Acre, Yield, and Total Supply

	Planted AC (Mil Ac)			Yield (units/Ac)			Total Supply (Mils)		
Crops	Baseline	Alternate Scenario	Change from the Baseline	Baseline	Alternate Scenario	Change from the Baseline	Baseline	Alternate Scenario	Change from the Baseline
	Million Acres		%	Units/Acre		%	Million Units		%
Corn (bu)	87.68	89.33	1.88%	190.00	229.54	20.81%	18,039.3	18,632.3	3.29%
Grain Sorghum (bu)	6.44	5.81	-9.84%	67.35	67.95	0.89%	425.06	366.61	-13.75%
Oats (bu)	2.56	2.44	-4.77%	69.05	69.78	1.06%	201.78	201.39	-0.19%
Barley (bu)	2.89	2.81	-2.88%	78.97	79.32	0.44%	279.72	267.44	-4.39%
Wheat (bu)	48.13	44.42	-7.72%	50.60	52.05	2.87%	2,899.11	2,649.94	-8.59%
Soybeans (bu)	91.67	96.81	5.60%	52.67	60.58	15.02%	5,152.22	5,328.44	3.42%
Cotton (lbs)	11.44	9.26	-19.09%	894.84	924.33	3.30%	**24.29***	**19.67***	-18.99%
Rice (cwt)	0.70	0.70	0.00%	8601.93	**8643.41****	0.48%	103.33	99.00	-4.19%
Hay (Tons)	54.50	54.49	-0.01%	2.38	2.38	0.00%	164.56	164.56	0.00%
Camelina (lbs)	0.00	30.31		0.00	595.69	-	0.00	17,145.00	-
Total All Crops	306.02	336.37	9.92%						

***Cotton supply units are in bales ** Rice Yield units are in pounds.**

Table 3. 3: Changes from Base Case to Alternate Scenario with Camelina Price of $0.25 per pound for Price and Net Return

	PRICE			Net Returns (Value-Expenses)		
Crops	Baseline	Alternate Scenario	Change from the Baseline	Baseline	Scenario (1)	Change from the Baseline
	$/unit		%	Million $		%
Corn (bu)	3.43	3.20	-6.96%	22495.22	24681.44	9.72%
Grain Sorghum (bu)	3.10	3.74	17.09%	150.61	380.78	-152.82%
Oats (bu)	2.26	2.23	-1.27%	33.78	42.72	26.48%
Barley (bu)	4.62	4.79	3.49%	422.94	450.17	6.44%
Wheat (bu)	5.05	5.55	8.98%	5067.83	6025.67	18.90%
Soybeans (bu)	9.65	9.33	-3.44%	28392.28	29623.17	4.34%
Cotton (lbs)	0.69	0.76	8.75%	254.94	963.72	-278.01%
Rice (cwt)	15.41	16.10	4.28%	566.00	518.11	-8.46%
Hay (Tons)	158.70	158.70	0.00%			
Camelina (lbs)	0.00	0.25	-		549.01	
Total All Crops				57383.61	63234.79	10.20%

Table 3. 4: Changes from Base Case to Alternate Scenario with Camelina Price of $0.50 per pound for Harvested Acre, Yield, and Total Supply

Crops (units)	Planted Acres			Yield			Total Supply (Mils)		
	Baseline	Market Price Scenario	Change from the Baseline	Baseline	Market Price Scenario	Change from the Baseline	Baseline	Market Price Scenario	Change from the Baseline
	Million Acres		%	Units/Acre		%	Million Units		%
Corn (bu)	87.68	92.39	5.37%	190.00	249.55	31.34%	18039.28	19589.33	8.59%
Grain Sorghum (bu)	6.44	5.58	-13.29%	67.35	67.66	0.45%	425.06	346.72	-18.43%
Oats (bu)	2.56	2.28	-10.85%	69.05	70.42	1.98%	201.78	205.50	1.84%
Barley (bu)	2.89	2.71	-6.33%	78.97	79.36	0.49%	279.72	255.28	-8.74%
Wheat (bu)	48.13	42.66	-11.38%	50.60	52.04	2.85%	2899.11	2492.56	-14.02%
Soybeans (bu)	91.67	96.49	5.26%	52.67	65.16	23.70%	5152.22	5159.00	0.13%
Cotton (lbs)	11.44	8.78	-23.26%	894.84	942.14	5.29%	**24.29***	**18.88***	-22.28%
Rice (cwt)	0.70	0.64	-7.94%	8601.93**	**8690.54****	1.03%	103.33	90.78	-12.15%
Hay (Tons)	54.50	54.50	0.00%	2.38	2.38	0.00%	164.56	164.50	-0.03%
Camelina (lbs)	0.00	44.66		0.00	536.72	-	0.00	22776.06	-
Total All Crops	306.02	350.70	14.60%						

***Cotton supply units are in bales**

**** Rice Yield units are in pounds.**

Table 3. 5: Changes from Base Case to Alternate Scenario with Camelina Price of $0.50 per pound for Price and Net Return

Crops	PRICE ($/unit)			Net Returns (Value-Expenses)		
	Baseline	Scenario 1	Change from the Baseline	Baseline	Scenario (1)	Change from the Baseline
	$/unit		%	$/unit		%
Corn (bu)	3.43	2.90	-18.06%	22495.22	22679.44	0.82%
Grain Sorghum (bu)	3.10	4.03	22.95%	150.61	449.56	-198.49%
Oats (bu)	2.26	2.14	-5.67%	33.78	53.72	59.05%
Barley (bu)	4.62	4.94	6.51%	422.94	467.17	10.46%
Wheat (bu)	5.05	5.90	14.50%	5067.83	6488.11	28.03%
Soybeans (bu)	9.65	9.62	-0.25%	28392.28	30922.56	8.91%
Cotton (lbs)	0.69	0.77	10.20%	254.94	1103.94	-333.01%
Rice (cwt)	15.41	17.43	11.61%	495.50	555.78	12.17%
Hay (Tons)	158.70	158.70	0.00%			
Camelina (lbs)	0.00	0.50	-		5881.19	
Total All Crops				57313.11	68601.47	19.70%

Table 3. 6: Plant Gate Cost for Oilseed Crushing facility for Camelina Oil

Oilseed Crushing, Extraction and Filtering Summary in 2017 dollars for Camelina	
Facility demand (pounds of oil)	96,300,000
Price ($/pound)	$0.28
Yield (pounds/acre)	1,050
Production (Gallons)	30,588,235
Name Plate Capacity (gallons)	30,588,235
Capital Feedstock ($)	0
Capital Transportation ($)	$118,915
Capital Conversion ($)	$84,737,080
Total Capital Costs ($)	$84,855,995
Total Capital Costs ($/gallon)	$2.77
Operating cost Conversion ($)	$16,774,047
Operating Farmgate Cost of Feedstock ($)	$26,885,998
Operating Cost of Transportation ($)	$666,396
Operating Credit ($)	-$1,293,184.00
Total Operating Cost	$43,033,257
Total Operating Costs ($/gallon)	$1.41
Total Cost per gallon	$4.18

Table 3. 7 Summary of Plant-Gate Costs in the Conversion of Camelina Oil to Green-Jet

Oilseed Crushing, Extraction and Filtering Summary in 2017 dollars for Camelina	
Facility demand (pounds of oil)	595,645,419
Price ($/KG)	$1.75
Yield (pounds/acre)	1,050
Production (Gallons)	32,999,746
Name Plate Capacity (gallons)	61320000.00
Capital Feedstock ($)	$21,328,404.00
Capital Transportation ($)	$118,915.00
Capital Conversion ($)	$9,805,686.00
Total Capital Costs ($)	$31,253,005.00
Total Capital Costs ($/gallon)	$0.95
Operating cost Conversion ($)	$6,614,435.00
Operating Farmgate Cost of Feedstock ($)	$179,023,622.05
Operating Cost of Transportation ($)	$666,396.00
operating cost of hydro processing	$36,011,556.00
Operating Credit ($)	-$1,293,184.00
Total Operating Cost	$221,022,825.05
Total Operating Costs ($/gallon)	$3.60
Total Cost per gallon	$4.55

Table 3. 8 Summary of Plant-Gate Costs in the Conversion of Camelina Seed to Green-Jet

Oilseed Crushing, Extraction and Filtering Summary in 2017 dollars for Camelina	
Facility demand (pounds of oil)	595,645,419
Price ($/KG)	$0.28
Yield (pounds/acre)	1,050
Production (Gallons)	32,999,746
Name Plate Capacity (gallons)	61320000.00
Capital Feedstock ($)	$21,328,404.00
Capital Transportation ($)	$118,915.00
Capital Conversion ($)	$9,805,686.00
Total Capital Costs ($)	$31,253,005.00
Total Capital Costs ($/gallon)	$0.95
Operating cost Conversion ($)	$6,614,435.00
Operating Farmgate Cost of Feedstock ($)	$5.04
Operating Cost of Transportation ($)	$666,396.00
operating cost of hydro processing	$36,011,556.00
Operating Credit ($)	-$1,293,184.00
Total Operating Cost	$41,999,203.00
Total Operating Costs ($/gallon)	$5.72
Total Cost per gallon	$6.67

Table 3. 9 Summary of Crop Enterprise Budget

2018 Field Camelina	Unit	Quantity	Price	Total
Revenue			**Gross Revenue ($/Acre)**	
Camelina	lbs	1050	$0.28	$293.15
			Total Revenue	**$293.15**
Variable Expenses				
Seed	lbs	5	$2.00	$10.00
Fertilizer	Acre	1	$45.30	$45.30
Chemical	Acre	1	$27.50	$27.50
Repair & Maintenance	Acre	1	$11.76	$11.76
Fuel, Oil & Filter	Acre	1	$8.50	$8.50
Operator Labor	Acre	1	$5.95	$5.95
Machinery Cost for broadcast Planting	Acre	1	$13.40	$13.40
Crop Insurance	Acre	1	$0.00	$0.00
Operating Interest [7]	Acre	1	$0.90	$0.90
Other Variable Costs	Acre	1	$0.00	$0.00
			Total Variable Expenses	**$123.31**
			Return Above Variable Expenses	**$169.84**
Fixed Expenses				
Machinery				
Capital Recovery	Acre	1	$27.08	$27.08
Other Fixed Machinery Costs	Acre	1	$0.00	$0.00
Taxes, Housing & Insurance	Acre	1	$5.96	$5.96
Other Fixed Costs	Acre	1	$0.00	$0.00
			Total Fixed Expenses	**$33.04**
			Return Above All Specified Expenses	**$136.80**

Table 3. 10: Breakeven Price for Selected Yield

Yield (lbs.)	Variable Cost ($/lbs.)	Total Specified Cost ($/lbs.)
450	$0.27	$0.35
600	$0.21	$0.26
750	$0.16	$0.21
900	$0.14	$0.17
1050	**$0.12**	**$0.15**
1200	$0.10	$0.13
1350	$0.09	$0.12
1500	$0.08	$0.10
1650	$0.07	$0.09

Table 3. 11 Breakeven Yield for Selected Price

Price ($/lbs.)	Variable Cost (lbs.)	Total Specified Cost (lbs.)
$0.18	688	873
$0.20	604	766
$0.23	538	682
$0.25	485	615
$0.28	**442**	**560**
$0.30	405	514
$0.33	375	475
$0.35	348	441
$0.38	325	412

Chapter 4: Conclusion

4.1: Conclusion:

It is important to assess the factors that affect wood pellet export as wood pellet production in the US is heavily dependent on export markets. Thus, a commodity-specific gravity model is assigned to examine the factors that affect wood pellet export from the US The LOG-LOG gravity model with two type of fixed effect is used with three demand Scenario. Two model are log-log gravity model with importer fixed effect, log-log gravity model with importer and time fixed effect. Each model estimate with three demand Scenarios. These three Scenarios assume three different demand scenarios in importing countries that discussed above. Monthly panel data of wood pellet export quantity from the US to 11 importing countries was used to examines the factors. The first essay concluded that the factors that affect US wood pellet exports are US GDP, demand for wood pellets in importing countries, US renewable energy policy which gives incentive to US wood pellet production, importer's research and development policy for their wood pellet production and barrier policy or the trade regulation policy for biomass. Among them US GDP, demand for wood pellets in importing countries, US renewable energy policy which gives incentive to US wood pellet production positively affect the US wood pellet exports where importer's research and development policy for their wood pellet production and barrier policy or the trade regulation policy for biomass negatively affect wood pellet export from the US.

The second essay examines the camelina an energy crop potential to supply renewable jet fuel. The US Federal Aviation Administration (FAA) has established a target for the US aviation industry to consume one billion gallons of renewable jet fuel each year beginning in 2018. Currently, 22 airlines are using alternative fuels over 200 commercial flights and the demand for renewable aviation fuel is rising. Already FAA approved five new renewable jet fuel pathways Thus, this study used a crop enterprise budget to determine the cost of producing camelina as a winter cover crop and determine the net return for a selected yield and camelina price. This budget also established the breakeven yield for the selected price and breakeven price for selected yield. A tornado diagram based on sensitivity analysis was also drawn to show how net return can change with different cost and revenue component changes. Furthermore, the EPIC model is used to calculate the average yield and standard deviation of yield throw-out the 305 POLYSYS regions. Finally, the POLYSYS model estimates the supply curve of camelina, based on different price scenarios of $0.05-$0.50. The results suggested that at the price level $0.30, 18903.17 million pounds of camelina seed is produced where 34.47 acres are planted for camelina and that produced 546.09 million gallons of renewable jet fuel. Finally, the camelina can supply 155.44 million gallons to 669.67 million gallons of renewable jet fuel based on different price level on an average.

Vita

Umama Rahman is from Dhaka, Bangladesh. She finished her undergraduate degree in Economics from North South University Bangladesh in 2014 with distinction. After her graduation, she worked in a research position before starting her master's program in Agricultural and Resource Economics with a concentration in Natural Resource Economics at the University of Tennessee Knoxville. After finishing this master's degree, she will go back to Dhaka, Bangladesh and plan to join in academia. She has the plan to pursue a Ph.D. in Energy Economics in near future in the USA.